COLLEGE OF ENGINEERING CORNELL UNIVERSITY

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the Cornell engineer

OCTOBER, 1955
VOL. 21, NO. 1
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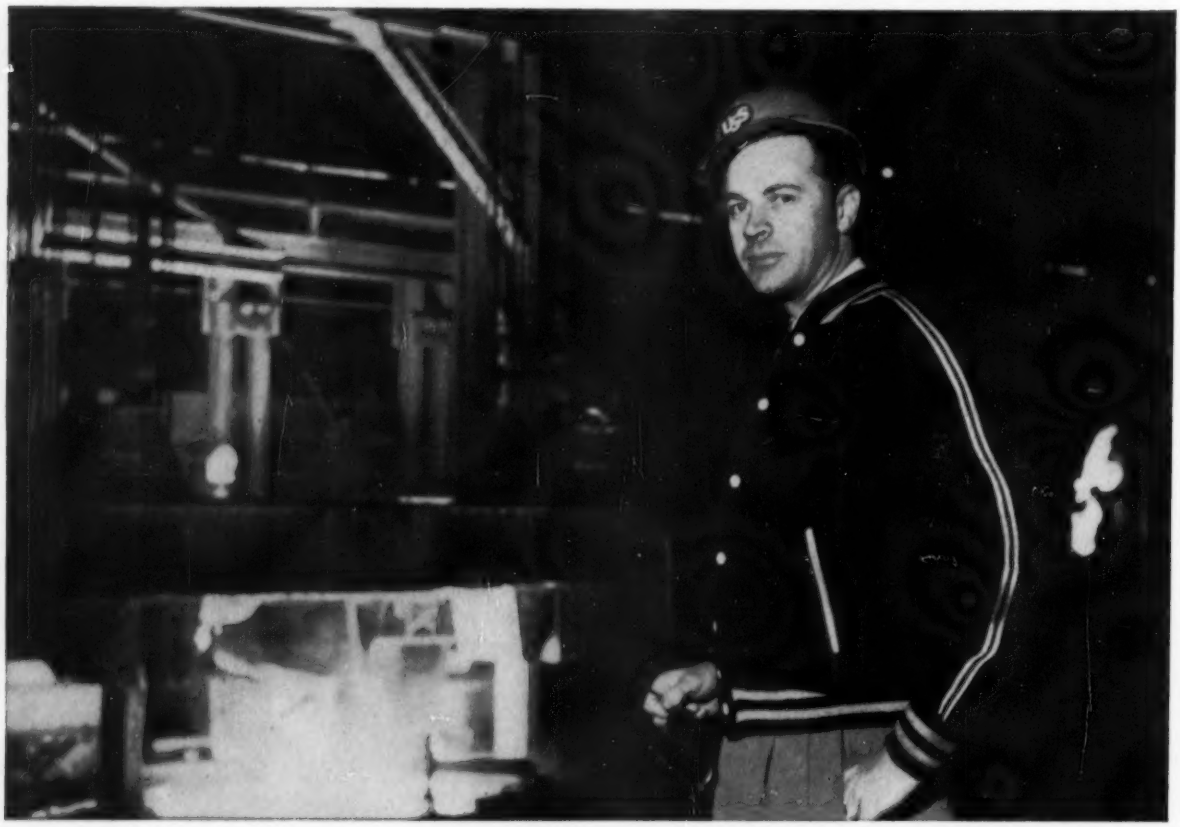

Immediately following his graduation as a B. S. in Metallurgical Engineering, Richard Crowell was recruited by the chief metallurgist of U.S. Steel's Clairton works. By 1951 he received his third promotion to Engineer-Operating Practices in the Open Hearth Division at Clairton. Recently he had his fifth promotion to his current position as Assistant Superintendent of Clairton's Open Hearth Department.

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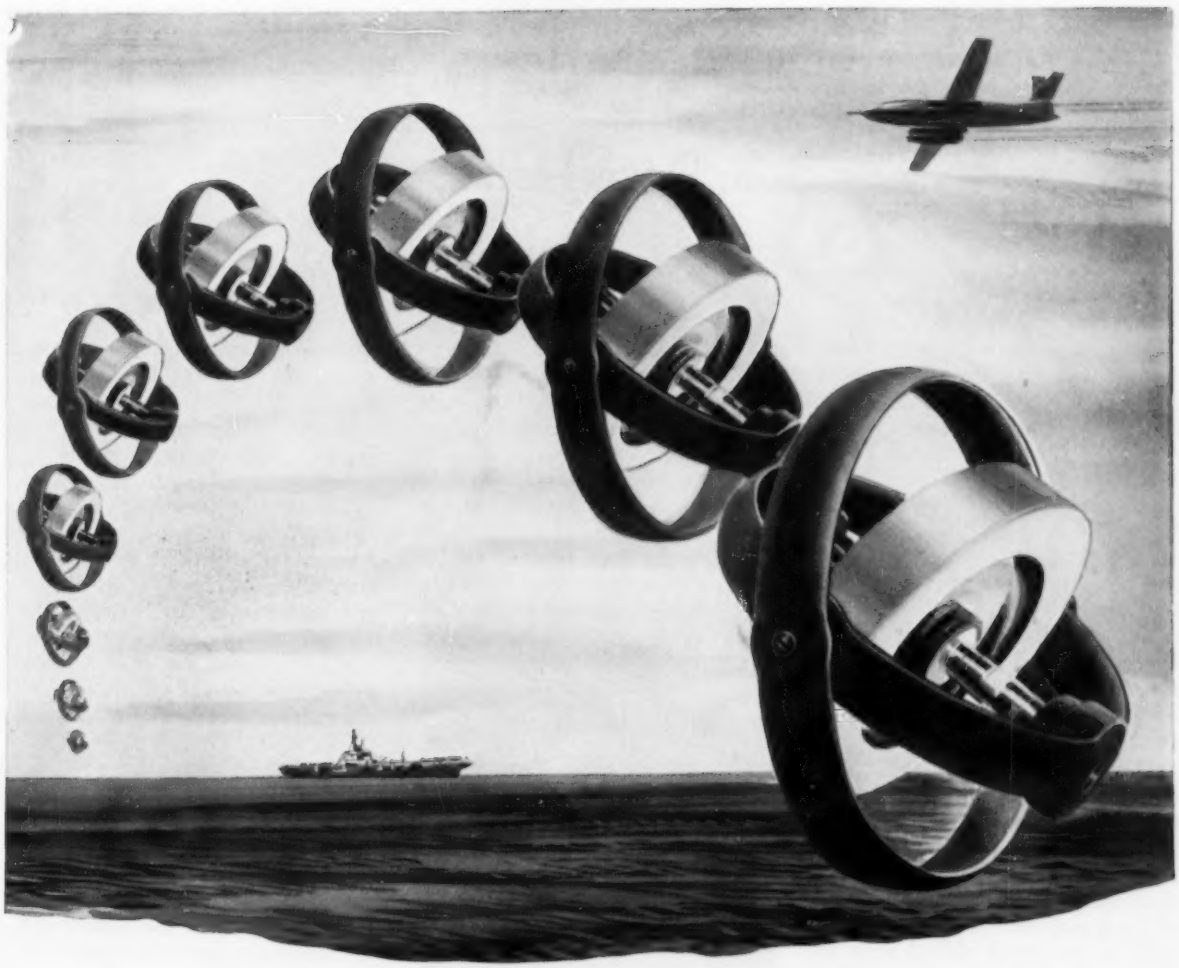

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A Welcome to the Freshmen from Dean Hollister

It is a pleasure to welcome you to Cornell as members of the Freshman Class in Engineering.

I am sure you realize that you are entering now the most important period of your preparation for a lifetime career. The direction and shape of your future very likely will be determined to a considerable extent in your next five years at Cornell — five years which constitute the most productive investment you can make for a successful career. I cannot urge you too strongly to keep in mind that in this time you must establish a foundation upon which you can build a professional life for forty years or more.

Looking this far into the future, to what pattern shall we plan your engineering training? The answer to that lies in the recognition that the engineer is no longer a highly individualistic, specialized technician. He is a professional man in every sense of the word, skilled both in the use of science for the solution of broad technological problems, and in the application of rational analysis to economic, social, and business affairs. So it is that, whatever your immediate field of interest may be now, you will probably find that your career will call you into many activities you cannot now anticipate.

You will find also that your scholastic training must have such firm roots that whatever advances in engineering may come about — and certainly such advances are occurring with increasing rapidity — you will have the background that will enable you to advance your own abilities with the growth of the profession, and in fact provide the leadership for that growth. This has been the Cornell tradition.

A final objective you must have in mind throughout your college career is this: that both through your formal study and your many activities outside the classroom you will accept the stimulation that is all about you for broad intellectual growth, so that you will be prepared to take leadership as a citizen in the whole range of human affairs as well as in your professional work.

In order to benefit fully from your association with Cornell, you should endeavor to become familiar with its distinctive personality and its historical development. There is much inspiration in the story of Cornell and I hope you will seek it out. You will find, for example, that at its beginning, Cornell represented a radical departure from the classical concept of higher education which would not tolerate the practical sciences as fit subjects for major study at this level. Ezra Cornell himself determined that training in engineering, science, and the humanities should stand side by side here, each benefiting from the others.

Dean Hollister

So it was that, within a very short time, Cornell engineers were taking a dominant part in the great industrial development and the great advances in transportation and communication which began about that time. This traditional role of the College continues to the present time. You will see around you the physical evidence of our planning for the future, with a number of new engineering buildings in use or under construction. Of even greater importance, however, is the Cornell of human beings, human ideas, and human enthusiasms. Your full participation in this fraternity will establish the return on your investment.

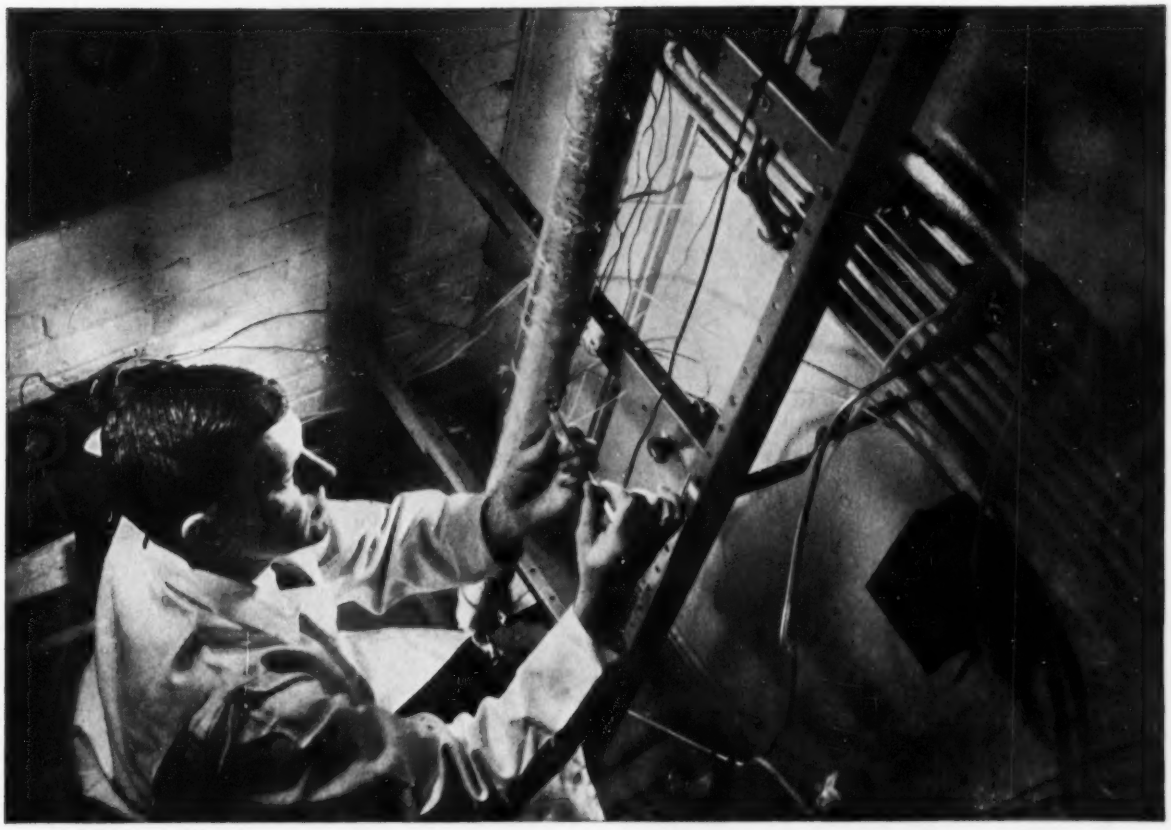
The engineering curricula at Cornell provide a superior educational preparation, second to none. They are designed to train for leadership and as such they are demanding of our best mutual efforts. I can assure you that we are determined to work with you in every way possible to bring about the most effective kind of educational experience.

It would be unrealistic, however, to expect that the path will be smooth and troublefree for all. It is likely to be the most challenging you have ever attempted, but by the same token also the most rewarding. For some the adjustment of these first few weeks may be difficult and perhap even momentarily discouraging, but I want you to know that we stand squarely behind you, asking in return your own sincerity of purpose. You have been chosen for the engineering program at Cornell on the basis of a highly selective admission procedure. We think you can become a Cornell Engineer, and our every effort is directed toward having you take your place in this distinguished family.

In urging you to your maximum effort I do not intend to sound an unnecessarily stern note. This is a joyous occasion and the beginning of one of the most happy and fruitful periods in your life. The opportunities for your personal development will be almost limitless. Cornell is a spiritual as well as an intellectual experience and I hope that you will take full measure of all that is here.

I congratulate you on the opportunity before you.

S. C. Hollister



The chemical engineer in an industrial laboratory has an unparalleled opportunity for expressing his individual interests and ability. The challenge of keeping ahead of an ever-changing technology is a difficult one to meet. The illustration shows the initial stages of a project on thermal diffusion of liquids.

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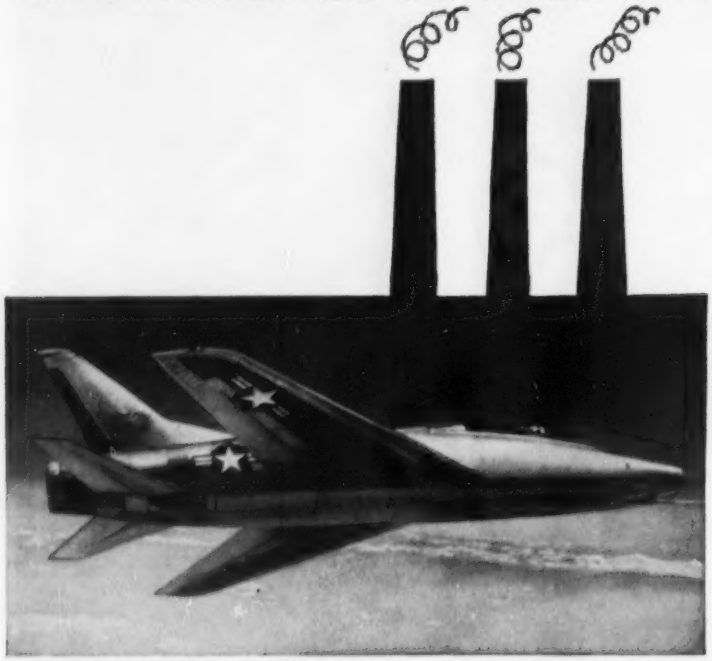

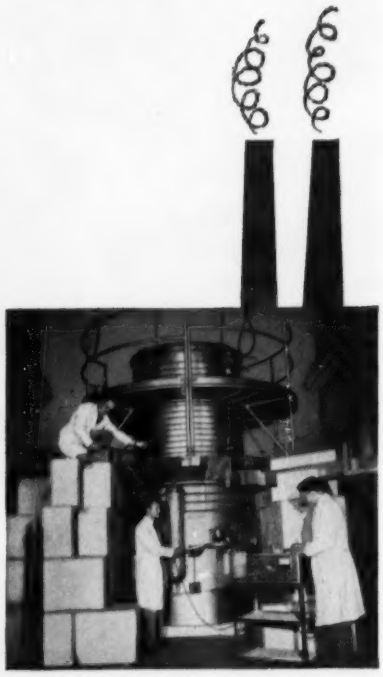

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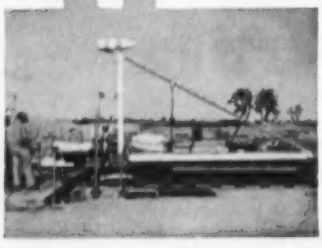

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An electric power transmission system, often covering several whole states, presents unexpected and messy problems in ac network analysis. These problems, their consequences, and solution, are discussed with special reference to Cornell's new Network Calculator in Phillips Hall.

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Except for nuclear powerplants, no other engine scheme has been conceived that is capable of the surprisingly high potential power levels and performance versatility of the ducted fan engine, here carefully discussed, by an expert in the subject.

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Experience with a number of misfortunes in aircraft flight has demanded that serious attention be given to fatigue failure of wing an dcabin structures. The basic problem is metallurgical involving inquiry into phenomena not recognized until recently as highly important.

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COVERPHOTO: Cornell's new A.C. Network calculator now in operation in Phillips Hall.—See article Pg. 9.

—*Photo Science*

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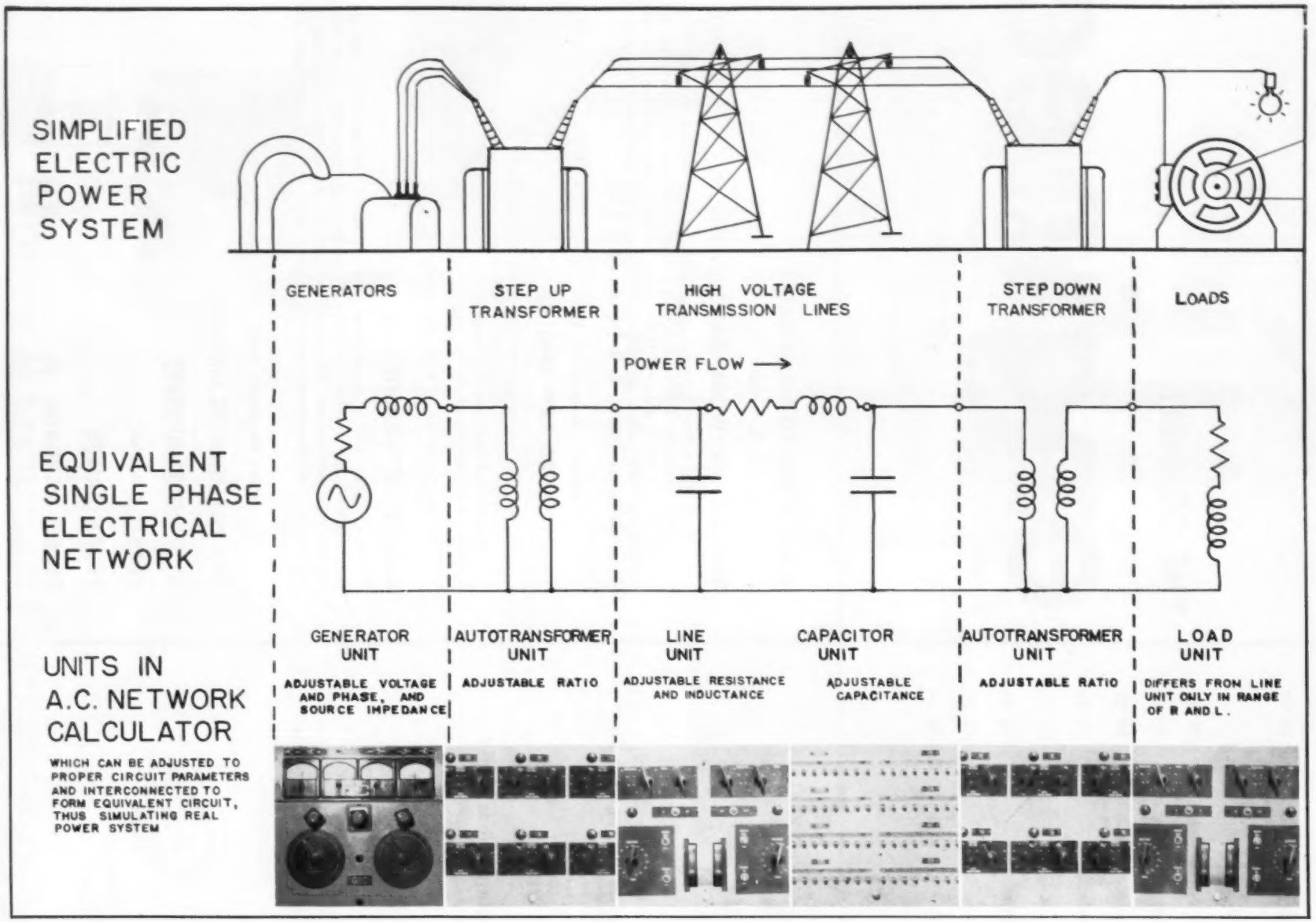
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UNITS IN A.C. NETWORK CALCULATOR
WHICH CAN BE ADJUSTED TO PROPER CIRCUIT PARAMETERS AND INTERCONNECTED TO FORM EQUIVALENT CIRCUIT, THUS SIMULATING REAL POWER SYSTEM

The A.C. Network Calculator

by Robert T. Braden, E.P. '57

Electric power is the lifeblood of our industrialized society. Our country is criss-crossed by an intricate network of high-voltage power transmission lines, each carrying millions of watts of electric power over the miles from generators to factories and cities. Power from falling water or from burning coal rotates the huge generators day and night; the power flows out over the transmission lines to substations, from which it is distributed to individual users over the familiar pole-lines. So vital is the continuing flow of electric power that home life and industries are largely paralyzed whenever storm or flood interrupts the flow for more than a few hours.

Electric power companies, both public and private, have the task of building and maintaining the generators and transmission lines so as to keep sufficient power flowing to their customers with no costly interruptions. Even without accidental occurences such as broken wires and overloads caused by lightning, flood, or storm, the task of distributing the power is a complicated one. The amount of power demanded by consumers in different parts of the network varies hourly, daily, and monthly, and the power fed into the network by the various generators must be adjusted accordingly. To complicate the situation further, two power are often connected by "tie lines," so that one company can help supply the other's peak load. The resulting network may cover one or several whole states.
systems serving adjacent territories

Each power system must be managed so as to keep the customers supplied at the smallest possible cost; furthermore, the demand is constantly increasing, and each proposed new line or generating station must be proved economically sound before it is constructed. To obtain the necessary information for running the system efficiently and for deciding upon future improvements, the companies must perform extensive "load studies," calculating the currents, voltages, and power flows in their networks for many different load conditions, and with any proposed new facilities simulated.

Left: Fig. 1. Simulation of power system by network calculator.

Fault Prevention Poses Problems

The power system engineer is not finished when he has provided for the regular flow of power to the customers, however. Heavy windstorms do blow lines and trees down, causing shorts, and lightning does frequently induce high voltage surges in the lines. These "faults" cause very heavy currents to flow, and could severely damage the transformers and generators; therefore, the engineer must build into the distribution network a complicated system of overload detectors and circuit breakers. When a particular line has a fault causing excessive currents to flow, the circuit breakers at each end of the line open to isolate it from the rest of the power system, which can then continue to supply nearly normal power. The fault is then said to have been "cleared" from the system. Since many faults, such as lightning strikes, are only momentary, the breakers are often set to wait a fraction of a second after they first open, and then try reclosing. If the fault persists, they will reopen and lock open. This reclosing action causes the momentary flickering which is sometimes seen in the lights during a thunderstorm.

Fault clearing, although simple in principle, is quite complex in practice, and sometimes leads to unexpected problems, as one power company discovered several years ago. This company, which we shall call the ABC Company, is a co-supplier of power to one of our large industrial cities; the other supplier, which we shall call the XYZ Company, is connected to the ABC Co. through a tie line. The ABC Co. had just completed a new station which was in operation feeding 130 megawatts of power into the system.

A workman was perched high overhead on a beam in one of the ABC substations, doing some routine repair work. Suddenly he made a nearly fatal mistake; he backed up too far, and a tool hanging from his belt shorted a "live" bus bar, carrying 22,000 volts. There was a bright flash; his safety belt was instantly burned through, and he fell to the ground. He was very fortunate; his fall was short and he walked away unhurt; but overhead pandemonium had broken loose. For some unknown reason, the original short, a simple "line-to-ground" fault, devoloped almost instantly into a much more serious

fault, with all three phases overloaded; this may have been due to arc-over, to faulty relays, or to several other possible causes. Even this more serious fault, however, should have been immediately cleared by the breakers on that line, allowing the rest of the system to continue to supply power to the other substations. What actually happened, however, was that the system voltages swung wildly for an instant and then all the breakers opened in the new generating station, which happened to be nearest the fault, cutting the new station completely from the system. When this happened, the rest of the generators of the system had to violently readjust to supply the power which the new station had been supplying. The disturbance was felt throughout the ABC system, and via the tie line, in part of the XYZ system as well.

The ABC Company was very much concerned over this accident; it showed that the new generating station could be put entirely off the system. The chance of this particular fault occuring again is of course remote; however, a lightning strike could easily cause an equivalent or even worse fault. In a few years, with the demand steadily increasing, more generators would be added to the new station, and then the consequences of the entire station going off could be severe. The rest of the system, trying to redistribute the power among the old generators, would be unable to bear the entire load and would probably become unstable, and the entire system would go out of commision, a rather serious breakdown. As the ABC system slipped out of synchronism it would "pull apart" from the XYZ system, and the breakers in the tie line would open, further aggravating the trouble.

The ABC Company engineers set out to discover why the new station had gone off the system, and whether the system might become unstable as a result. They had graphs from automatic recording machines telling exactly when the important breakers opened and closed; using this information they hoped to be able to reconstruct the entire sequence of events. This was not an easy task, however, for the disturbance involved all of the ABC system and part of the XYZ system; together their systems covered a large part of the state. Investigation showed that under such conditions the whole system might easily have become unstable, and engineering changes have been made to prevent the instability from arising in the future.

The ABC Company's problem, the stability of their system, is a common one. All power companies must carefully investigate their systems for possible instability under every conceivable type of fault, and learn how to set their circuit breakers and voltage regulators to prevent such instability.

Calculator Solves Load, Stability Problems

We have now mentioned two types of problems which are of vital importance to power companies: load studies and stability studies. Solution of these problems for all except unusually simple networks would be difficult or impossible without the use of A.C. (Alternating Current) Network Calculators. These machines are large and impressive, usually filling large rooms with panel boards covered with meters, knobs, dials, and switches. An A.C. Network Calculator is simply a power system in miniature; that is, it can be set up to duplicate the essential features of a large and intricate power distribution system, with generators, transformers, transmission lines, and loads all represented. The high voltage and currents of the actual system are scaled down to convenient low ranges in the calculator; the calculator's meter readings can easily be scaled up to give the voltages and currents which the actual power system would have under the assumed conditions.

Cornell University has recently purchased an A.C. Network Calculator from the Westinghouse Electric Corporation. Westinghouse built this particular Network Calculator in 1942, at which time it was the largest one in existence. There are now about thirty three A.C. Network Calculators in the country, and only five or six of them are larger than the Cornell machine. Therefore, its acquisition is an important forward step for the Power Systems Engineering Department of the Cornell Electrical Engineering School.

Last July the installation of the machine in a specially designed room in Phillips Hall was completed, and the calculator was placed in operation. The cover photograph shows the Calculator in operation

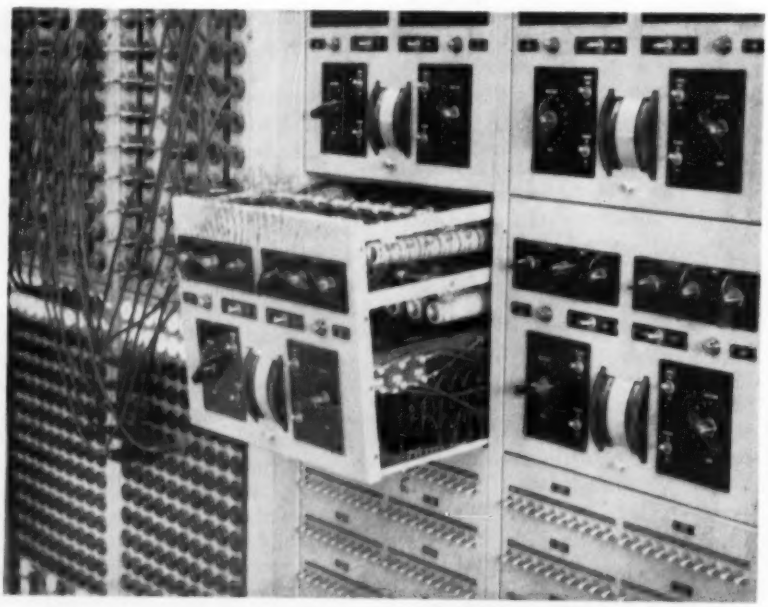

Fig. 2. Units of calculator are built into individual drawers for ease of installation and replacement. Drawer shown partly open is a line unit.

in Phillips Hall. The machine's use will be rented to power companies for their load studies, stability studies, etc., at the rate of $200 a day. It is hoped that it will pay for itself over a number of years. The day-to-day operation of the machine is handled by its chief operator, Lawrence B. Spencer. Mr. Spencer, formerly an instructor in the Electrical Machinery Laboratory, had six months experience with this Calculator while it was still at Westinghouse.

Network Calculator Has Research, Instruction Role

The Calculator's primary function will be as a service to power companies; however, under the direction of its supervisor, Simpson Linke, a large proportion of its time will be used by the staff of the Power Engineering department for educational and research purposes. Mr. Linke, an Associate Professor in the field of Power Engineering, hopes to use up to a third of the machine's time for graduate and faculty research and for instruction and demonstration in power engineering courses. The instructors of these courses have long realized that many of the computing problems given to students in power engineering are so long and involved that the students tend to get lost in the pages of slide-rule computations; however, simpler problems would not adequately demonstrate the points which the instructors wish to get across to the students. The Network Calculator may be used by these classes as a "giant slide-rule" to take the drudgery out of the calculations and allow the students to understand what is really going on. For the advanced courses it will provide valuable experience in load and stability studies on complicated power systems.

Power System Operation Simulated

How does the Network Calculator "work?" Its principles are very simple. It has units which simulate electrically all the units of an actual power system: generators, transformers, lines, capacitors, and loads. These units can be connected together to simulate a particular power network, and the voltages, currents, impedances, and powers can be adjusted to duplicate on a small scale those of the actual system. Meter readings taken on the units of the Calculator will then tell what the corresponding values in the actual system would be under those same conditions. A fault, or a proposed generator or line can be added to the network set on the Calculator, and the engineers can then tell just what effect it has on the power distribution system.

For convenience of operation the Calculator units are calibrated in percentages of full-scale, or "base" quantities. For example, if the normal voltage of the system under study is 50 KV (Kilovolts), a base voltage of 50 KV might be used for that study. Then a calculator meter reading of 100% voltage would indicate 50 KV, while 60% voltage would indicate 30 KV, and so forth. The current, impedance, power, and volt-amperes are similarly expressed as percentages of base quantities. The operator can easily convert these percentages read from the Calculator to the quantities in the actual system. In the Calculator, 100% voltage is actually 100 volts, and 100% current is one amp, but the operator need not be aware of these values; he can work entirely in terms of percentages of quantities in the actual power system.

The Calculator contains eighteen Generator Units, each of which can simulate electrically a generator in the system. Each unit is an adjustable A.C. voltage source; at its terminals appears a voltage whose magnitude is adjustable from 0 to 300%, and whose phase is adjustable over 360°. Both adjustments are made by simply turning calibrated dials on the front panel. These units are not actually generators, but are rather adjustable transformers simulating generators. The primaries of all the Generator Unit transformers are fed with a 440 cycle A.C. voltage from a common Calculator supply bus. The secondaries are connected thru the phase shifter and thru adjustable impedance units to the output terminals. The impedance units represent the internal impedance of the simulated generators, and are calibrated in percent ohms impedance.

It is interesting to notice that the Calculator uses 440 cycle power instead of the 60 cycles of the actual system. This makes no difference in the operation, but the higher frequency makes the inductors and capacitors smaller and lighter, and thus reduces the size and weight of the entire calculator.

To simulate transformers there is a set of tapped auto-transformers, the proper taps being selected by switches on the panel. To simulate power-factor correction capacitors or loads with leading power factors there is a set of capacitors of different values. Switches on the panel can be set to insert the desired capacitive reactance into the circuit. To simulate line drops and inductive loads there are many resistor-inductor units, called Line Units and Load Units according to their function. The difference between the two types is mainly that the Line Units contain a much lower range of impedance than the Load Units. Finally, long transmission lines are represented by their approximately equivalent "pi" networks, with series inductance and resistance shunted at each end by capacitance to ground; these are incorporated in Pi-Line Units.

The individual units are built into largely self-contained drawers, which slide into the panel. If necessary, a particular drawer can be replaced easily by a new one. Figure 2 shows one of the Line Unit drawers partly opened.

The actual interconnection of the various units to represent a particular power system is done very quickly and easily, by a jack and plug system, as shown in Fig. 3. In setting a network up on the Calculator, considerable simplification is usually done, and approximations are made. For example, in most cases three phase power transmission systems are close enough to being balanced that only one of the phases need be represented on the Calculator. Identical generators or motors operating at the same point in the network are replaced by one equivalent machine; series impedances are lumped as much as possible into one line or load impedance; and so forth. Knowing when one can make these approximations and when one can't is largely a matter of experience; there have been notable cases where the approximations

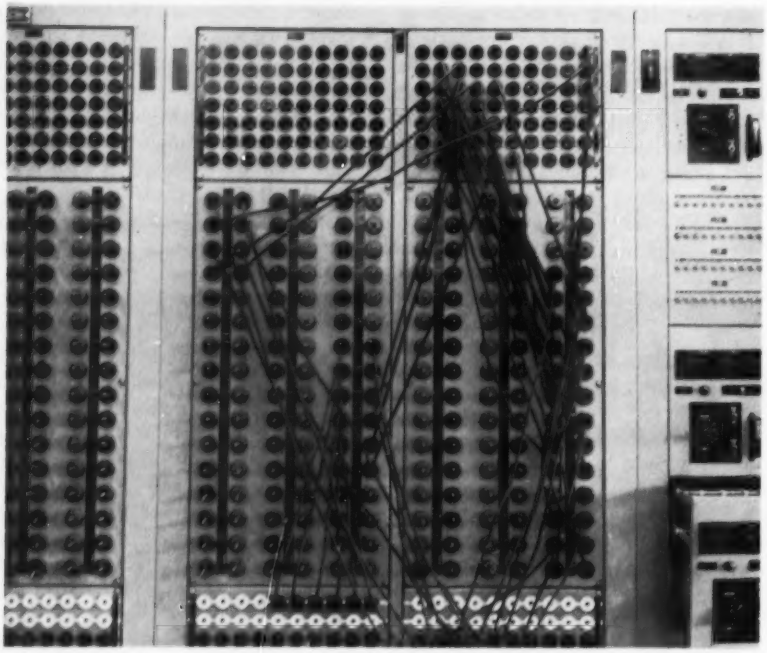

Fig. 3. Jack and plug system speeds connecting units to simulate complete power system.

were too broad and resulted in the Calculator's giving the wrong answer. These approximations are necessary, however, for without them the solution of state-wide networks would be completely impossible, and the Network Calculator would have to be impossibly large, heavy, and slow to use.

Centrally located in the room are the two Control Consoles (see cover photography). The two consoles are independent so that two different operators can use different Calculator components for different problems at the same time. The Consoles contain sets of master instruments which allow the operator to meter any circuit in the entire calculator without leaving the Console. That is, by operating a set of push-buttons, the operator can connect the master instruments to read the current, voltage, power, reactive power, and phase angle of any unit in the Calculator, whether it is a generator, transformer, line load, or capacitor unit.

Next to one of the Consoles is the Plotting Table, a sloping surface on which a diagram of the system under study can be attached. The procedure for taking data is very simple; the operator at the Console switches his master instruments to each of the power circuits which he desires to "meter," and reads off the desired values; an assistant at the Plotting Table writes these values directly on the system diagram beside the generator, line, or load to which they apply. The point in the power network to which the master meters are connected is indicated by a light showing thru the plotting table top under the corresponding point in the diagram. These indicator lights, whose position is changed for each new system, ensure that the data is not recorded at the wrong point on the diagram.

Load studies are handled very simply by the Calculator. In a typical problem, a company might wish to know the effect of adding a new generator station to the network. The system, including the proposed generator, is set up on the Calculator by plugging together the necessary generator, line, etc., units, and setting the switches and dials for the proper impedance and voltage values. For a particular assumed set of loads, the power flows, voltages, and currents in the key lines and loads are read and recorded. This is repeated for different loads and perhaps for different locations and capacities of the proposed generator. A new copy of the system diagram is used for each set of data, to avoid confusion.

Stability Studies Involve Transient Conditions

Load studies are relatively simple and straightforward on an A.C. Network Calculator because they are steady-state problems; that is, the RMS values of the currents and voltages are constant with time. Stability studies, on the other hand, belong to the much more difficult class of transient problems in which the time variation of the RMS values must be studied. A power system is unstable if, when a disturbance is applied to the system, one or more of the rotating machines (generators and motors) ceases to rotate at synchronous speed and falls out of synchronism with the rest of the system. This is dangerous, for it causes very high reactive currents to flow and could severely damage the apparatus. Under normal operation a generator is stable; any small variations in speed of rotations caused by normal load variations are opposed by the magnetic field in the machine, tending to keep it rotating in exact synchronism with the other generators in the system. The mechanical power input to a generator is controlled by a governor which responds very slowly to changes in load; therefore a sudden change of load is felt first as a torque trying to accelerate or decelerate the generator rotor. If the disturbance on the system is severe, as a fault, one or more of the generators may have its speed changed beyond the limits of stability, and will then slip out of synchronism. If the breakers clear the fault from the system quickly enough, the generators will not have moved out of the stable region and will pull back into synchronism; if they wait too long one of the generators may slip beyond the stable point and will go out of synchronism even if the fault is then cleared.

A transient stability problem is solved on a Network Calculator by considering the power system instant by instant, and assuming that during each instant it is in a steady state. This is only an approximation, but if the instants are made short enough, .05 seconds or less, it gives the correct answer. The original network is set up on the Calculator and the fault is simulated

by actually grounding the corresponding point in the Calculator set-up. Power readings are then taken from the Calculator, giving the power demanded of each generator by the fault. This additional power acts to decelerate the generators, the amount of deceleration being determined by the moment of inertia and original angular velocity of each rotor. An approximate numerical integration procedure is then used to determine the change of velocity and angular displacement which would result from this acceleration acting throughout the instant; this is computed for each generator in the system. This procedure is repeated for each instant in succession, and the phase angles of the generators in the Calculator network are readjusted at each instant according to the angular displacements computed during the preceeding instant.

At the proper instant the breaker's opening, clearing the fault, is simulated by disconnecting the corresponding circuit on the Calculator. Any succession of breakers opening and reclosing in different parts of the network can be simulated in this manner. After the fault has been cleared, all stable machines will be seen to be pulling back into synchronism, while any unstable machines will continue to pull out of step.

This step-by-step procedure is usually repeated many times, for different load conditions, different faults, and different time delays in the breakers. The power company learns from these runs the conditions under which the system might become unstable, and how to set the breakers to avoid it.

Synchronous Switch Produces Repeating Transients

Another type of problem involving transient behavior occurs in studying the effect of lightning on transmission lines. This problem is encountered by the designers of power apparatus, learning to make better lightning arresters and circuit breakers. To facilitate this type of study, the Westinghouse engineers have built an accessory to the Network Calculator, which they call a Synchronous Switch. This Switch is essentially a set of commutators rotated by an electric motor. The lines and other circuits whose transient behavior are to be studied are set up on the Network Calculator. The Synchronous Switch is then used to initiate the transient phenomenon repeatedly many times a second, so that it can be observed on an oscilloscope. Cornell hopes eventually to add such a Switch to their Network Calculator.

Calculator Gives Load Dispatching Solutions

Another type of problem, which is just beginning to be successfully solved, is that of Economic Load Dispatching. This study seeks the answers to the question: how should the loads be divided among the different generators in a particular system to provide power to the customers at the lowest possible cost per Kilowatt-hour, taking into account the losses in the different lines and differing costs of power production at the different generator stations in the system? The answer may be different for each different set of loads, and will vary with the price of coal at the different stations or with the amount of water available at hydroelectric plants. This type of problem is a difficult one, about which there is still a great deal to be learned. The only practical method of solution for large networks involves using the Network Calculator to solve the network for many different power flows, and then using one of the modern electronic digital calculators to compute the line losses and find the optimum power distribution for each condition.

Load studies and stability studies continue to be the most important problem to power companies attempting to provide power as efficiently as possible with no costly interruptions. Even with the recent advances in all types of calculators, it seems unlikely that the A.C. Network Calculator will be soon replaced as the easiest method for solving these problems. Cornell's Electrical Engineering School can expect from their Network Calculator many years of useful service to industry and education in the power engineering field.

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THE DUCTED FAN ENGINE

by ISRAEL KATZ

The ducted fan engine, essentially the only type of aircraft turbo powerplant capable of efficient operation over wide speed and altitude ranges, has tremendous future potential for subsonic and supersonic flight. The CORNELL ENGINEER is privileged to publish for the first time this general appraisal of the ducted fan engine, written by a recognized authority, Professor I. Katz.

At this very moment almost every major aircraft engine builder in the world has a ducted fan engine either in some stage of development or under intensive study. The reason for this activity, which is feverish in certain quarters, is a renewed realization that one of the earliest forms of turbojet engine inherently possesses the attributes required of turbo-powerplants for the propulsion of aircraft at hitherto unattainable speeds. Data bearing upon the factors and effects relating to the use of ducted fan engines for powering supersonic military vehicles cannot be discussed here. It should suffice to say, however, that the subsonic and transonic versions of the engine are similar in principle to the supersonic types, although the details of construction and operation differ.

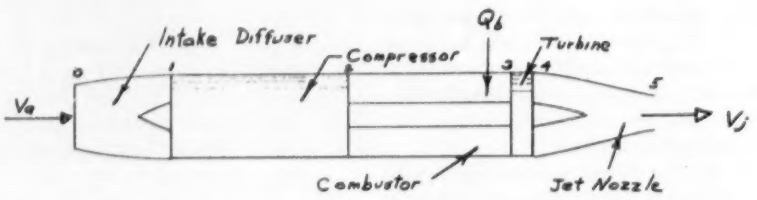


Fig. 1. Conventional Turbojet Engine.

There is little basically new about ducted fan engines other than the recognition (which is in part intuitive) that, when built and operated along appropriate lines, they may afford performance capabilities and versatility that cannot be matched, over the same ranges of operating conditions, by any other type of aircraft powerplant. In addition, certain ducted fan engine designs seem admirably suited for use with boundary-layer air induction techniques that may permit unusual reductions of airframe drag at very high flight speeds (the engine uses boundary-layer air as the working medium and restores its kinetic energy at least to the full free-stream level, thereby eliminating the resistance associated with the boundary-layer wake)[1].

General Propulsion Principles

All aircraft gas turbines effect propulsion of their flight vehicles by the acceleration of air in a direction opposite to the direction of flight. In the case of turbojet engines, figure 1, the ambient still air approaches the engine with a relative velocity U_a, which is the airspeed of the flight vehicle. After being compressed, heated and expanded, the air leaves the engine with velocity U_n, which is the jet nozzle discharge velocity relative to the engine.

The compressor is used to raise the pressure level of the air, above the relatively low ram-pressure lev-

ABOUT THE AUTHOR

Professor Israel Katz obtained his BSME from Northeastern University, and after doing graduate work in experimental and automotive engineering at Cornell, received his MME degree in 1944. He joined the faculty at Cornell in June 1942 as a civilian member of the U. S. Navy Diesel Engineering staff, where he lectured on propulsion problems and worked in the area of main propulsion machinery for submarines. After he joined the Department of Automotive Engineering in 1946, he taught courses in aircraft engine design and organized the former Aircraft Powerplants Laboratory at the Cornell Airport. Professor Katz has done consulting work for Pratt and Whitney Aircraft and General Electric Company. As a member of the Department of Thermal Engineering of the School of Mechanical Engineering, he teaches courses in combustion engines and gas turbines.

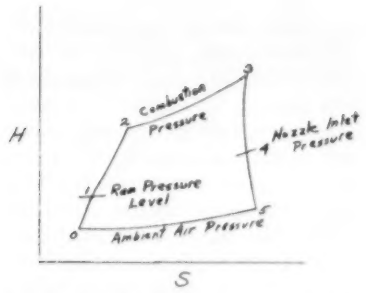


Fig. 2. Enthalpy-Entropy diagram for the conventional turbojet engine.

el, not only to permit the addition of heat to the air in sufficient quantity and with proper rapidity within the confines of the engine to make practical and efficient engine operation possible, but also to provide sufficient pressure drop across the jet nozzle to develop significant propulsive forces.

The function of the turbine is to drive the compressor. However, since a pressure drop in the flow also is required across the jet nozzle to convert the flow's sensible enthalpy into kinetic energy, the drop of total pressure across the turbine should be less than the rise in total pressure across the compressor. This pressure drop requirement is brought out in figure 2. Neglecting the effects of pressure losses associated with the mechanical operation of an engine, viscous friction in the flow and minor differences in the weight rates of flow through the compressor and turbine (due to the addition of fuel to the air in the combustors), the change of enthalpy across the turbine must equal the change of enthalpy across the compressor. Thus the overall change in specific kinetic energy of the flow effected by the engine must be equal to the corresponding net difference between the sums of specific enthalpy changes occurring in the flow beyond the combustors on the one hand, and ahead of the combustors on the other. The relationship that applies here may be written as

$$\frac{U_j^2 - U_a^2}{2g} = (H_4 - H_5) - (H_3 - H_0),$$

where $H_3 - H_4 = H_2 - H_1$,

or $\Delta KE_{0-5} = \Delta H_{3-5} - \Delta H_{0-2}$.

On this basis it would seem that the thermal efficiency of the engine should be equal to its conversion efficiency

$$\eta_c = \frac{(H_4 - H_5) - (H_1 - H_0)}{H_3 - H_2} = \frac{U_j^2 - U_a^2}{2gJQ_b},$$

where Q_b represents the corresponding chemical energy released during combustion (assuming complete combustion of the fuel).

However, the above relationship only partially describes the effectiveness with which the chemical energy in the fuel is utilized to produce propulsive work.

The specific change in momentum experienced by the air in passing through the engine is only $U_j - U_a$. Therefore, from the second law of motion, the specific thrust developed is

$$T = \frac{(U_j - U_a)}{g}$$

and the specific propulsive work is

$$W_p = TU_a = \frac{(U_j - U_a)U_a}{g},$$

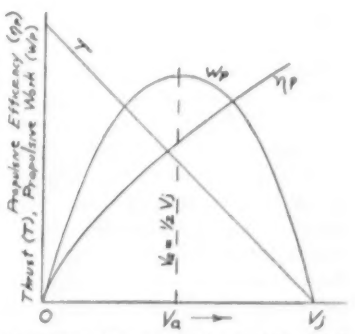


Fig. 3. The theoretical effects of the flight vehicle's airspeed (V_a) on the thrust, propulsive efficiency developed by the engine for a fixed value of jet gas exit velocity (V_j).

which is only part of the change in the specific kinetic energy produced in the flow by the engine. The ratio of effective propulsive work to the corresponding change in kinetic energy of the flow is known as the propulsive efficiency

$$\eta_p = \frac{(U_j - U_a)U_a/g}{(U_j^2 - U_a^2)/2g} = \frac{2U_a}{U_j + U_a},$$

and the thermal efficiency of the engine becomes

$$\eta_t = \frac{(U_j - U_a)U_a}{gQ_b}.$$

It becomes clear then that the ratio

$$\frac{(U_j^2 - U_a^2)}{2gJQ}$$

represents the cycle efficiency, whereas the ratio

$$\frac{2U_a}{(U_j + U_a)}$$

is similar to an engine efficiency term.

Thus, the thermal efficiency of the engine also can be written as

$$\eta_t = \left(\frac{U_j^2 - U_a^2}{2gJQ_b}\right)\left(\frac{2U_a}{U_j + U_a}\right).$$

Figure 3 summarizes several important conclusions that may be drawn about the performance of turbojet engines. For a given jet exit velocity U_a, these conclusions are:

1. The thrust falls off linearly, with increase of vehicle airspeed, from a maximum value (when the vehicle is at rest) to zero (when the vehicle is moving with an airspeed equal to the jet exit velocity of the accelerated air relative to the engine).

2. The propulsive efficiency increases from a value of zero at

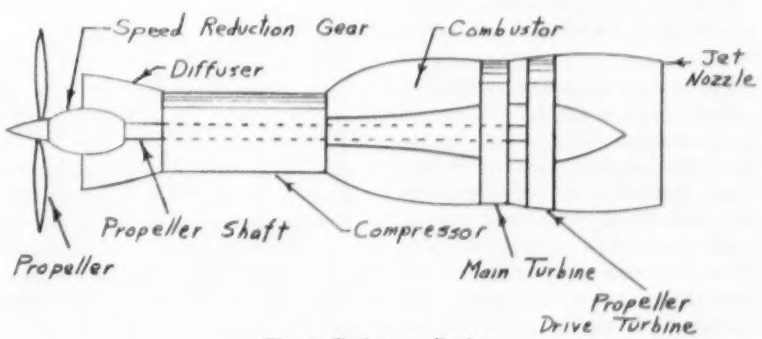


Fig. 4. Turboprop Engine.

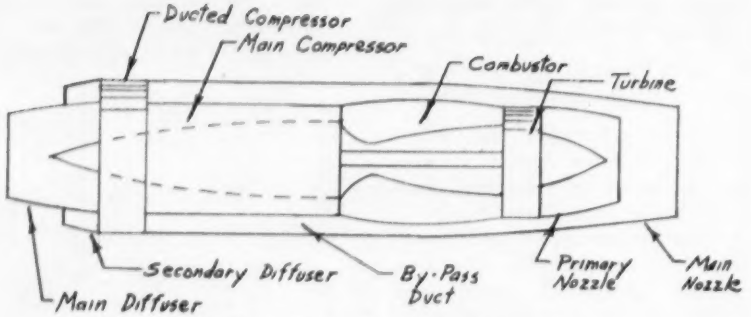


Fig. 5. Simple "by-pass" type ducted-fan engine.

maximum thrust to a value of 100% where $U_a = U_j$ and the thrust is zero.

3. The propulsive work is zero both when the thrust is a maximum with zero propulsive efficiency, and when the propulsive efficiency is 100% with zero thrust.

4. The propulsive work has significant value when neither the thrust or the propulsive efficiency is zero, and peaks at a value of U_j that can be determined by differentiating W_p with respect to U_a.

Thus, from

$$\frac{dW_p}{dU_a} = U_j - 2U_a = 0,$$

W_p is a maximum when $U_a = \frac{U_j}{2}$.

The Present Competitive Situation

On the basis of the above conclusions, it should be evident that to produce a high thrust with a turbojet engine, it usually is necessary to compromise propulsive efficiency and operate the engine at a propulsive work level less than optimum. It is current practice to operate turbojet engines at values of propulsive efficiency below 47% and at corresponding values of propulsive work below 85% of maximum.

The values quoted are sobering indeed. They serve to explain, in part, some of the practical limitations affecting the economy of turbojet engines. The turboprop engine, illustrated in figure 4, is generally intended to mitigate the poor thrust-economy relationships of turbojet engines by expanding the heated flow mainly across an extended turbine section (to drive a conventional aircraft propeller) rather than through a jet nozzle.

Since a properly matched propeller can accelerate a much larger quantity of air than is processed by its engine during a given interval of time, the propulsive work and propulsive efficiency of the propeller-engine combination can be raised without compromising high thrust. In fact, the use of a variable pitch propeller greatly increases the flexibility of operation so that high values or thrust, propulsive efficiency, and propulsive work can be realized over almost the whole schedule of aircraft operating altitudes and flight speeds. Moreover, the abilities of the propeller to not only blow air over the airplane's wings, and thereby produce significant lifting forces even at zero airspeed, but also reverse pitch, and thereby provide aerodynamic braking during landings, are important factors favorable to the adoption of the turboprop engine as an important powerplant.

Were it not for the good economy, high reliability and endurance, relative low weight, rapid power response, low cost and flexibility of conventional piston engines, the turboprop engine would eventually dominate the medium-speed (200-550 mph) and moderate-altitude (10,000-25,000 ft.) commercial service field.

Early optimism with regard to the general application of gas turbines to transport service has been dampened markedly by the realization that fully reliable and competitive gas turbine-aircraft combinations are many years rather than months away. From the very beginning of jet propelled flight, critical observers predicted that the turboprop engine would have little to offer in the way of performance that can not be provided in like measure by power-equivalent piston engines. Continued confidence in piston engine powered transport aircraft is expressed by the principal airlines of the world in terms of orders now outstanding for such aircraft to the amount of well over one billion dollars. The airlines that have placed these orders have committed themselves to piston engine propulsion and its associated profits well into the 1960's. There can be little doubt that the present use of turboprop engines by any airline will constitute a dangerous drain of its financial resources.

Of course, there seems to be no question, insofar as the public is concerned, that all aircraft will be powered eventually by some sort of gas turbine. In a sense, there is a fair likelihood that this will be so. However, behind the scenes a struggle is now in progress between the dyed-in-the-wool gas turbine enthusiasts and those who, spurred on by considerations of survival in a very complex area of business enterprise, must take what appears to be a conservative view of the situation, but which in reality constitutes sound discretion and a fully

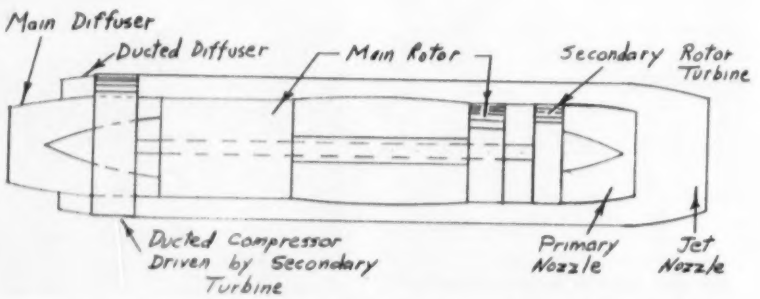


Fig. 6. "Two-spool" version of the by-pass type ducted-fan engine.

informed as well as practical approach toward the solution of their operating problems. The facts that influence the decisions of most airlines and constitute the crux of the present propulsion situation are these:

1. The average airline passenger trip is 500 miles and this distance has not changed since the beginning of commercial aviation.

2. Non-stop transcontinental flights, even at moderate airspeeds, are very expensive and a headache to the airlines, but are provided mainly for publicity purposes. Similar flights at even higher speeds and altitudes are not only frought with unforeseen dangers (as brought out in the recent Comet investigations), but would be prohibitively costly to the airlines unless very high premium fares were charged.

3. The piston engine powered airplane is a surprisingly competitive machine at moderate airspeeds and there is little or no compulsion to change from them at this time. The variable pitch propeller makes the supercharged and compounded piston engine the most versatile of powerplants whose performance can be approached by the turboprop, but hardly excelled.

4. Military and commercial experiences with turbojet engines demonstrate their abilities to propel large aircraft at high speeds, but the same experiences also show that a great deal of improvement in engines and aircraft is necessary before the public can have the same confidence in jet aircraft as it now has in the conventional types.

5. The jet engine dominates the high subsonic and supersonic flight speed ranges, but regular commercial flight at these speeds seems ludicrous at present; considering the expense and only marginal savings of time. Perhaps a new type of airplane and somewhat unique engine is required before the public can be asked to patronize jet propelled commercial transports.

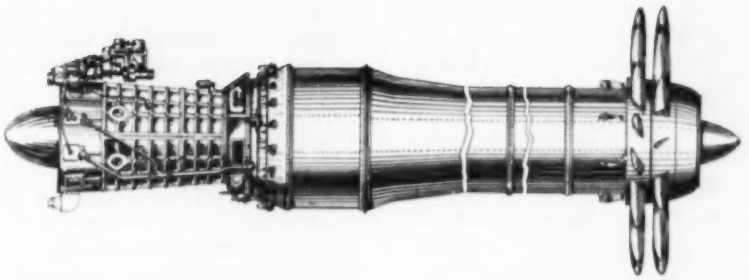


Fig. 8. The Metropolitain-Vickers F5 Open Fan Augmented Turbojet Engine.
—Metropolitan-Vickers Electrical Co. Ltd.

Thrust Augmentation By Gas Dilution

The ducted fan engine was conceived originally as a means for increasing the thrust developed by aircraft gas turbines without the encumberances of a propeller, and without compromising propulsive efficiency or degrading thermal efficiency. The thrust boost was to be achieved by accelerating a greater weight of air than is processed normally through conventional turbojet engines of comparable thrust power, but to discharge the greater weight of flow at a lower jet exit speed. It does not follow, however, that an increase in the mass flow rate of air, which is ultimately discharged at a lower jet speed, necessarily results in a thrust boost. The trick is to increase mass flow faster than the jet exit speed is reduced. In order to handle a greater weight of air, without reducing the engine's cycle efficiency or raising the combustion temperature above allowable limits imposed by the turbine blades, it was necessary to process only part of the total air through the combustors. The general pattern that evolved embraces the merging of compressed diluent air with the pressurized hot gases issuing from the engine's turbines, and the subsequent expansion of the mixed flow through a jet nozzle to produce propulsive thrust. This scheme permits maintenance of the highest allowable combustion temperatures in the primary flow and the consequent attainment of favorable fuel economies.

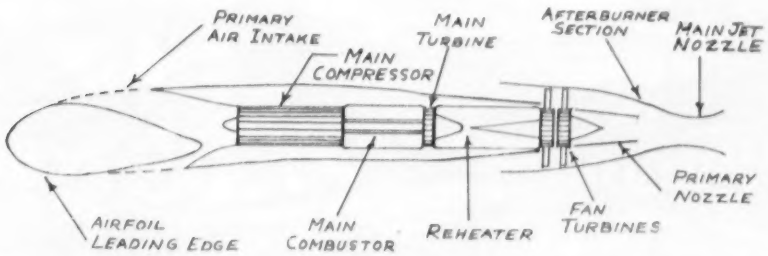


Fig. 7. A 'compound-reheat" ducted-fan engine system arranged to provide menas for boundary layer entrainment.

It was inevitable that several methods for processing the diluent air would arise and that some confusion regarding terminology should result (aggravated, no doubt, by the recent use of the term "ducted fan" to describe an ingenious "vest-pocket" helicopter). At this writing there is fairly general agreement that all aircraft gas turbines that achieve thrust augmentation by merging relatively cold compressed air with the turbine efflux should be called ducted fan engines because the diluent air compressor, although turbine driven, is usually operated in a duct type stator which leads to the jet nozzle. However, the term "by-pass engine" has crept into the picture and is used to identify specifically those ducted fan engines in which a portion of the air that enters the main-compressor section of the engine is bled from a low-pressure stage and by-passed around the combustors and turbine, but subsequently merged with the primary discharge from the turbine section.

In essence then, the ducted fan engine is a thrust-augmented turbojet in which thrust boost is

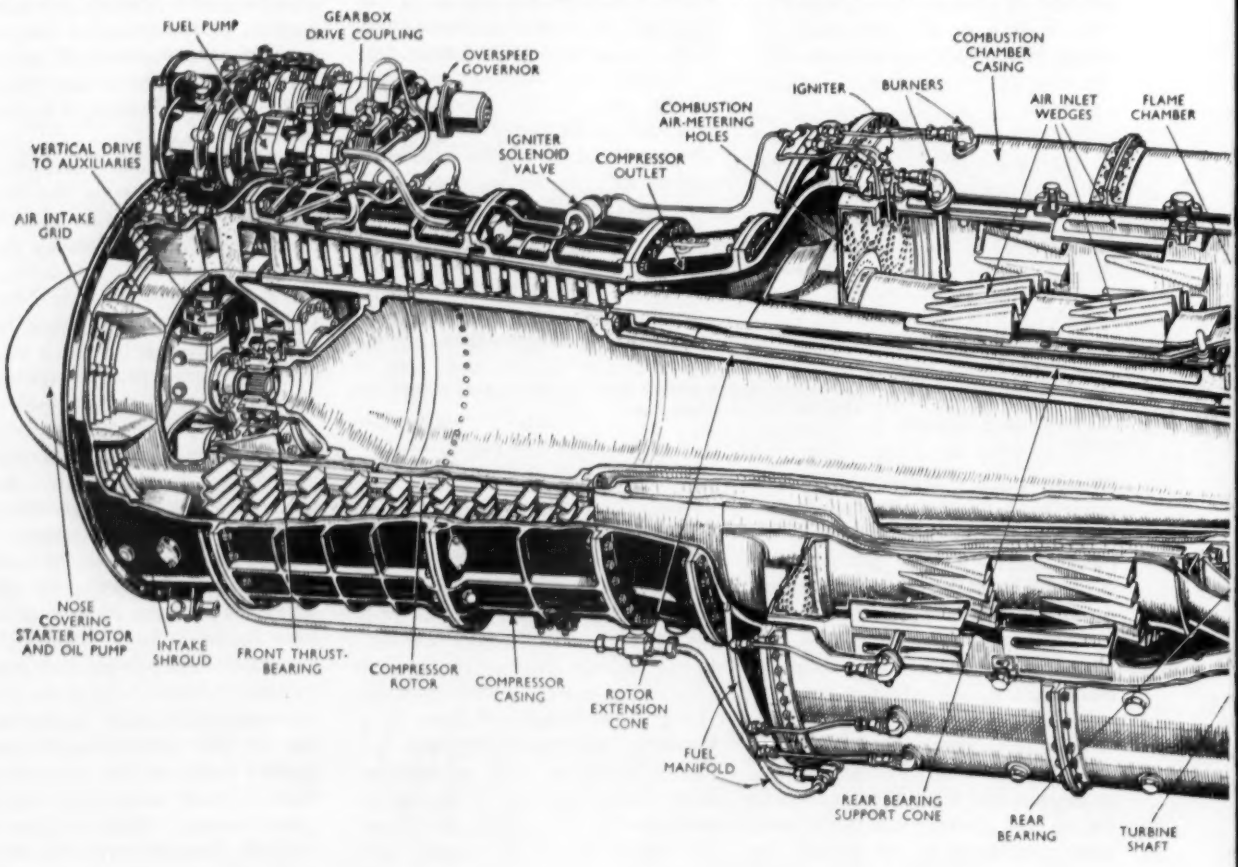
achieved by increasing the mass of air accelerated per unit time, but at some compromise in engine weight and complexity. The secondary compressed air is merged with the gases issuing from what otherwise would be discharge of a conventional turbojet engine. This diluent air can be compressed in several ways. The two principal methods will be considered with a view to examine their merits and to see where they fit into the general scheme.

Probably the better known but less versatile types of ducted fan engines are those being built or being contemplated along the lines illustrated in figure 5. Here the first few stages of the main compressor are extended to pump an appreciably larger quantity of air than that which passes through the remaining compressor stages. The diluent air is bled from the early stages, ducted around the combustors and turbines, and merged with the main hot gas stream at the discharge of the primary jet nozzle.

This type of engine is similar to conventional turbojet engines in the sense that it achieves its optimum performance only at a single design-point operating condition. Deviation from design-point operation introduces very serious degradations of economy and thrust unless afterburning is employed. While the engine can develop a higher thrust than its corresponding turbojet without compromising propulsive efficiency, the expected maximum gain in over-all aircraft performance, considering the higher weight of the engine, consists only of either a 5% increase in flight range at the same flight conditions or about a 5% reduction in fuel consumption for a given flight schedule. Few persons concerned with the propulsion of heavy transport aircraft are impressed by these predicted gains, but engines built along the lines of the simpler by-pass engine, such as the Turboméca Aspin II, may create a stir in the executive type aircraft field.

The engine illustrated in figure 6 may afford an interesting extension of high performance over a much broader range of engine operation than its simpler version and also permit use of the engine to propel a larger variety of aircraft[3]. The principal design disadvantage of the engine is its use of a concentric double-shaft compressor drive, which may require an extension in length of the engine's rotor section. Moreover, because the secondary compressor feeds air to the main compressor, the ar-

Fig. 9. The Metro-Vick F3 Ducted Fan Engine. The thrust augmentor is shown close coupled to gas generator, section of the engine.



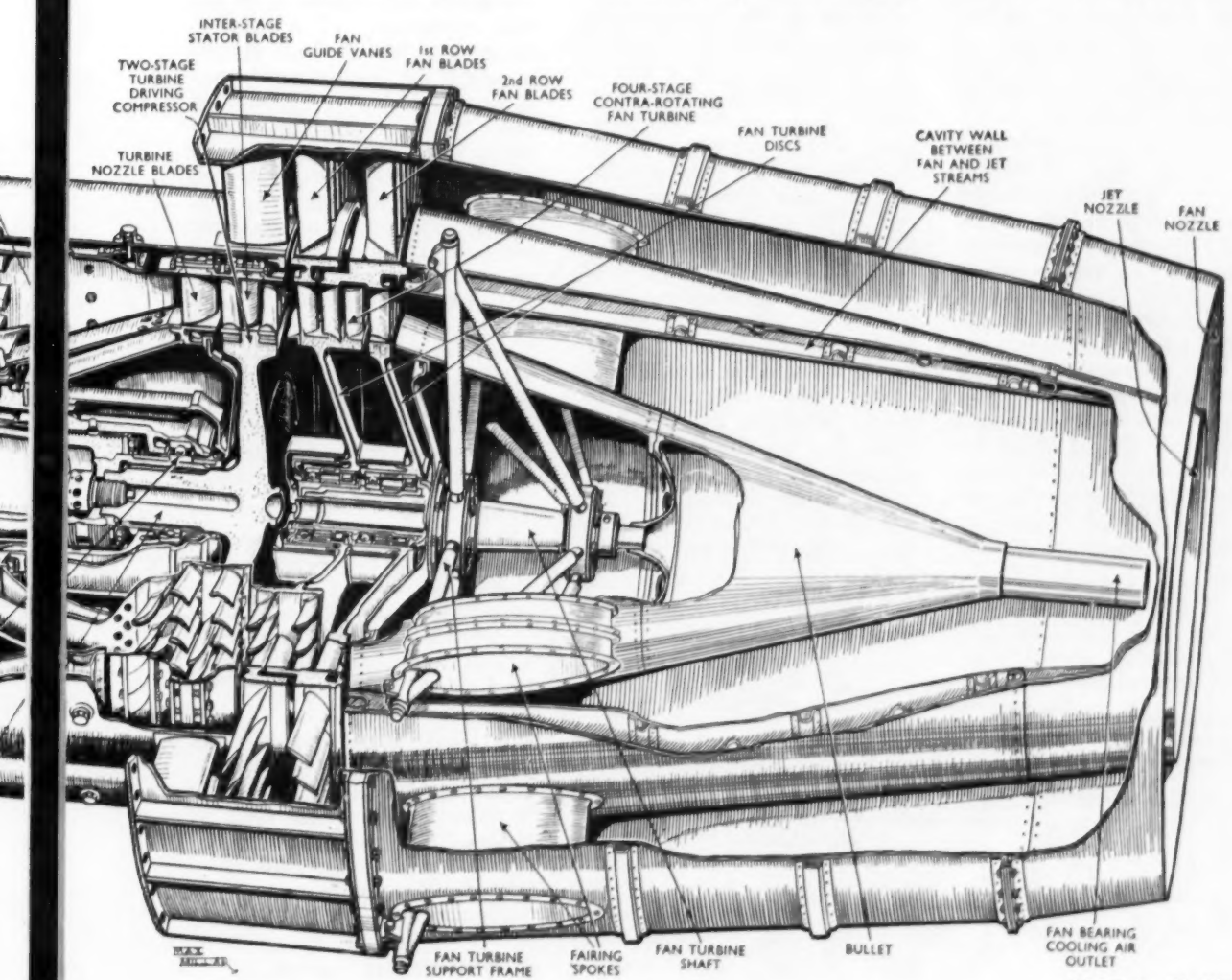
rangement may tend to be somewhat unstable; it may require considerable time to regain steady-state operation after flight conditions are changed abruptly. The enlarged front end of the engine will preclude its use for aircraft propulsion at very high speeds due to the fast drop in the thrust-drag ratio that such enlargement involves at high airspeeds. Although complete details of construction have not been announced, there is reason to believe that the forthcoming Rolls-Royce Conway is being built along the lines of the engine illustrated in figure 6. Such an engine would, in all likelihood, permit a normal thrust (or range) boost of approximately 5% over conventional turbojet engines of equal weight. It also may afford versatile performance at all altitudes up to 50,000 feet and within the speed range of 200-400 mph, at relatively low altitudes, or within the speed range of 400-600 mph at high altitudes. Its eventual application to combat vehicles is doubtful unless further compounded either with a "floating" thrust augmentor, fan stream heater, an afterburner or by some combination of these three thrust boost devices.

The second and perhaps lesser known type of ducted fan engine is illustrated in figure 7. Here a conventional turbojet engine feeds hot pressurized air to a set of contra-rotating turbines. The turbines, in turn, drive a group of contra-rotating fans fastened to the peripheries of the turbine wheels. The primary flow is merged with the compressed diluent air at the discharge of the primary jet nozzle and the resulting gas mixture is further expanded through the main nozzle to produce propulsive thrust.

The thrust augmentor, consisting of the integral turbine-compressor section, ducts, and nozzles is shown located downstream of a secondary combustor that provides a reheat function. An afterburner operating in the jet nozzle section of the thrust augmentor could produce additional thrust boost. While the overall length of the engine may exceed the length of any other aircraft powerplant, separation of the thrust augmentor from the gas generator avoids the critical shaft deflection problems associated with the by-pass type engines and provides invaluable flexibility and versatility essential for wing installations.

Origins of the Ducted Fan Engine

The ducted fan engine, as it is now conceived for subsonic and supersonic propulsion, stems from the outstanding work done during World War II by the Metropoli-



—"Flight" Apr. 25, 1946

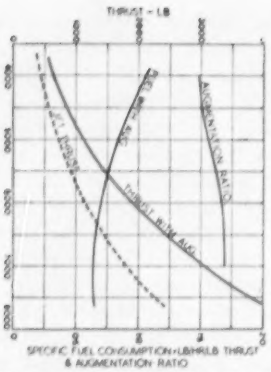


Fig. 10. Results of Metro-Vick F3 Ducted Fan Engine showing effects of main rotor speed on sea-level thrust augmentation. —"Flight" Apr. 25, 1946

tan-Vickers Electrical Company of Manchester, England. One of the first developments by this firm was an open-fan augmentor that was coupled to its F.2/4 turbojet as shown in figure 8. The open-fan augmented engine was designated the F.5 and designed to have thrust boosts of 1.48/1 and 1.56/1 (as compared with its F.2/4 basic element) during cruise at 400 mph and climb at 200 mph respectively, while flying at 20,000 feet. On the basis of bench tests, its cruise fuel consumption at 20,000 feet was determined to be 0.872 pounds per thrust pound hour and the engine achieved this noteworthy performance at a 30% increase in weight above the F.2/4. This was followed quickly by development of the Metro-Vick F-3 ducted fan engine. These successful engineering achievements gave impetus to an intensified government sponsored program in the United States devoted to the development of a similar engine. This program was conducted by the Aircraft Engine Division of the Packard Motor Car Company and was terminated about six years ago. The composition of the F-3 is illustrated by figure 9 and its principal characteristics are given in figure 10.

Design Criteria

While the ducted-fan engine is potentially one of the most efficient types of aircraft turbo-powerplants, both for subsonic and high supersonic aircraft propulsion, it can be demonstrated that their economies are destined to be critically sensitive to the mass flow ratio of primary air to diluent air. Should the ducted compressor be mechanically coupled to the main rotor, optimum performance will be restricted to a single design point. Intriguingly versatile performance may be attainable if the ducted compressor were mechanically independent of the main rotor. For subsonic commercial transport service both the by-pass and the thrust augmentor types of ducted fan engine are particularly interesting, but engines of the Metro-Vick F.3 type give the greatest promise for economical operation over an extremely wide range of power levels and flight conditions without the encumberances of formal diluent airflow control. It can be shown that, where the thrust augmentor turbines "float" in the gases issuing from the main turbine and where the ducted fans do not influence the pressure level in the combustors, the dilution ratio will adjust automatically, rapidly, and correctly to any change in engine operation, providing that the engine is designed appropriately.

As it is for all reaction propulsion devices that accelerate ambient air to develop propulsive thrust, a guiding criterion of design for economic operation is achievement of a jet discharge speed equal to twice the required flight speed. However, the key to realization of the remarkable performance capabilities of the ducted fan engine is operation with optimum dilution of primary discharge by secondary air because only with optimum dilution will it be possible to obtain economical operation without compromising thrust or propulsive efficiency.

Determination of required steady-state optimum dilution ratios is a matter of analysis and experimental tests. Principles related to the pertinent analysis, and the influential factors affecting the highest economy dilution ratios, may be illustrated with reference to figures 11, 12, and 13 as follows:[4]

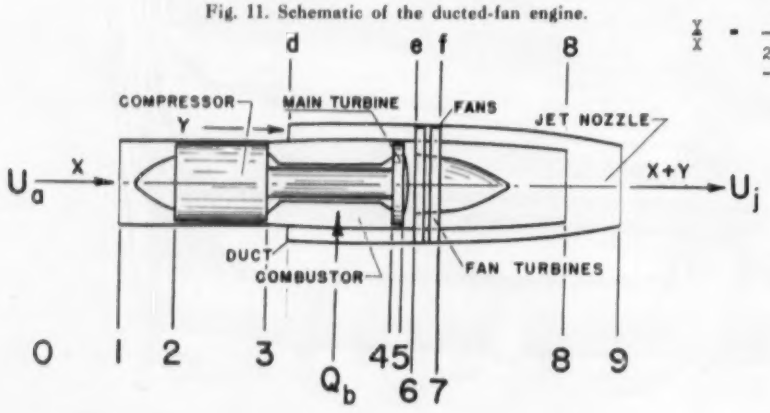
The energy converted across the main turbine must always equal the energy required to drive the main compressor and is equal to the energy added by the main compressor to the flow passing through it. Similarly, the energy converted across the fan turbines must equal the corresponding energy change in the secondary flow passing through the fans. The dilution ratio, Y/X is then selected in such manner that after the primary flow X and the diluent flow Y are merged at station 8 and subsequently expanded through the jet nozzle, the gases leave the engine with a relative velocity equal to twice the airspeed of the flight vehicle. The optimum value of Y/X for the non-reheat case may be expressed in terms of the principal independent design and operating variables as:

$$\frac{Y}{X} = \frac{\eta_{en}\,\eta_b\,F\,HV_p\left(1-\frac{1}{R_{en}^{\frac{k-1}{k}}}\right)}{\frac{2U_a^2}{g}-\eta_{en}\left(c_p T_o+\frac{U_a^2}{2g}\right)\left(1-\frac{1}{R_{en}^{\frac{k-1}{k}}}\right)}-1,$$

where

- η_{en} — Jet nozzle expansion efficiency
- η_b — Combustion efficiency
- F — Fuel/air weight ratio
- HV_p — Heating value at constant pressure of the fuel
- R_{en} — Jet nozzle expansion ratio
- U_a — Airspeed of the flight vehicle
- g — Gravity constant

Fig. 11. Schematic of the ducted-fan engine.



T_o = Ambient air temperature
c_p = Specific heat at constant pressure of the ambient air
k = Ratio of specific heat at constant pressure to the specific heat at constant volume of the ambient air.

General Conclusions

The ever increasing appeal of higher flight speeds coupled with an understandable reluctance of the traveling public to pay premium fares poses a dilemma for the airlines. Considering the relatively short distance travelled by the average passenger, the demand for frequent service between points and the economic necessity to operate at favorable palyoad grossload ratios, leaves the airline little alternative but to avoid turbojet propelled aircraft for the present.

It remains to be seen whether the airlines will eventually be in a position to offer turbojet aircraft service even on a premium fare basis. Indications are that conventional turbojet engines do not lend themselves admirably to commercial service, but there is reason to believe that ducted fan engines, of either the thrust augmentor or bypass types, may eventually make gas-turbine propelled aircraft competitive.

For the short haul, piston engine aircraft will continue to provide the principal services. The turboprop engine could be operationally competitive, but because it is a somewhat specialized powerplant and expensive, it is doubtful whether it will be built in sufficient quantity and size variety to become important. In the long run, however, the coupling of thrust augmentors to existing turbojets (that are already being produced in large numbers and varieties) may place subsonic jet propelled aircraft within the financial reach and confidence of the traveling public.

Subsonic and transonic ducted fan engines could make it possible for transport aircraft to operate at higher levels of economy and at much more suitable ranges of flight speeds, distances, and altitudes than are profitable with turbojets. Moreover, any given thrust augmentor design can be modified to

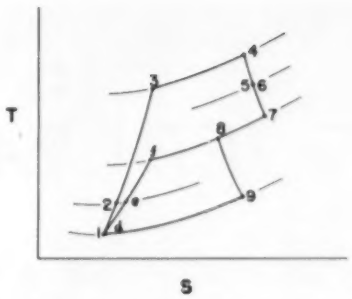


Fig. 12. Temperature-Entropy diagram for the ducted fan engine cycle.

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match the propulsive requirements of a relatively wide variety of aircraft and their flight schedule patterns.

From an operational standpoint ducted fan engines would impose no new fuel requirements, involve no special controls other than those used with conventional turbojets, and run noticeably quieter than turbojet engines as a result of exhaust flow dilution and lower jet gas exit speeds.

There can be little doubt that the attractive capabilities of ducted fan engines, even now, extend the horizons of commercial aviation well into high subsonic and transonic speed ranges. The development burden, therefore, falls upon the airframe builders who are expected to apply their skills to the design of aircraft that will utilize to the full the unusual performance of the ducted fan engine.

In military aviation, there is a constant tactical need for ever increasing flight speeds, sustained full-power operation at sea level and at extreme heights, and high performance at all flight conditions. On the whole, aircraft and engine builders did not see until quite recently how these desirable objectives could be met, even in part, by any combustion engine-aircraft combination. Ducted fan engines, particularly those of the thrust augmentor types that lie at the threshold of the ram jet, give promise for meeting this pressing need. This type of engine may well avoid the formidable airframe resistance forces (thermal barrier) now associated with very high flight speeds by the advantageous utilization of its large frontal area and greater length to swallow boundary air and thereby benefit further from the higher density of the entrained boundary-layer air as a supplement to the engine's mass flow. Furthermore, the abilities of this type engine to develop very high takeoff thrust, propel aircraft economically at subsonic cruise speeds and when necessary to provide tremendous thrust boosts for supersonic speed bursts, despite some compromise of fuel economy, places it in an extraordinarily favorable position. In fact, there are valid reasons to believe that at very high flight speeds, the internal Mach numbers of the engine would be beneficially low, as a result of the air ram temperature rise. Thus, despite the application of reheat, afterburning or fan stream heating (combustion in the diluent air), the propulsion efficiency would remain high and the economy of the engine would be comparable to that of the ram jet at very high speeds.

It would be premature, if not unreasonable, to say that the ducted fan engine alone is capable of propelling military vehicles at very high speeds, and at all altitudes up to about 70,000 feet, with fair economy and respectable engine life. However, at this moment, no other engine scheme is in sight, except the nuclear powerplant at extremely long range, that is capable, even in theory, of approaching the surprisingly high potential power levels and performance versatility of the compound-reheat ducted fan engine.

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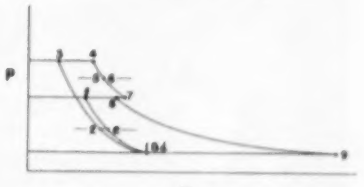
Fig. 13. Pressure-Specific Volume diagram for the ducted fan engine.



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COMET JET CRASHES:

Focus for Problems in Aviation Metallurgy

by ROBERT HENDRICKS, MetE '59

On January 10, 1954, the British Overseas Airways Corporation's new silver jet liner Comet G-ALYP took off from Rome's Ciampino Airport for London. Her nose lifted from the runway and she was airborne. Within a few minutes she was a black dot high above the horizon.

During the next half hour the radio operator in the Ciampino central tower kept contact with the Comet. After every report he recorded her position and altitude, and from his figures it was obvious that the plane was climbing to her 40,000 foot cruising altitude, just as scheduled.

The pilot of a slower propeller-driven BOAC Argonaut heard the Comet-to-tower conversation, and in between the jet's position reports contacted the plane to request high altitude weather data. Suddenly the Comet radio operator was cut off. There was silence.

Peasants on the Isle of Elba momentarily looked up at the speck high above the Mediterranean, then returned to their work. Four persons who continued to watch the plane saw the silver speck burst into flames and hurtle toward the sea. In a matter of minutes, the last bits of the broken craft slipped beneath the waves.

As a result of the accident all of the new Comet series were grounded during an investigation of possible danger sources. A thorough check of all the planes required making over fifty modifications before they could be put back into service. Even with these new modifications and improvements a second Comet crashed into the Mediterranean. This accident was very similar to the first one. The plane was climbing to her cruising altitude when she suddenly exploded.

Immediately following the second accident, all of the Comets were taken out of operation, and their air worthiness licenses were revoked. Four months later, after thousands of hours of research and investigation, the cause of the accidents was announced as a metal failure in the pressure cabin skin. Many people concluded that the metal was no good, and that metallurgists were to blame for the accidents. This popular explanation, proposed by non-specialists trying to solve a specialist's complex problem, was entirely wrong. In order to understand exactly what happened to the planes, it is necessary to consider the beginning of the crash investigations, and to consider man's fundamental knowledge of metal failures.

—British Ministry of Transport and Civil Aviation

Fatigue test apparatus for complete Comet aircraft.

Comet Wreckage Evaluated

Study of the Comet accidents was undertaken at the request of the British government by the Royal Aircraft Establishment at Farnborough, England. The R.A.E. solution of the accidents is one of the most remarkable jobs of scientific sleuthing in history.

The wreckage of the first Comet was brought up from six hundred feet of water by Royal Navy divers. The divers were able to recover the bodies of fifteen of the thirty-nine passengers, as well as nearly 70

per cent of the plane itself.

A coronary examination of the bodies showed that all of the victims had died in the same manner—each had received unexplainable skull fractures. In addition, each victim suffered from rapid lung decompression.

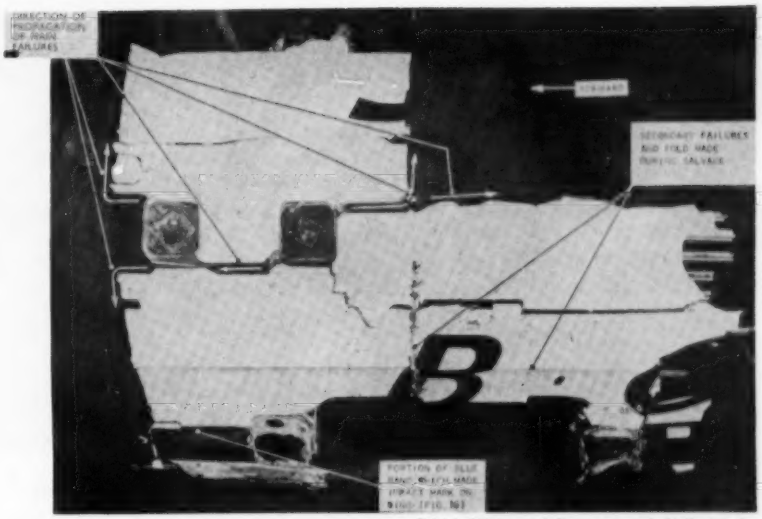
Careful examination of the wreckage revealed that only some portions of the plane had burned. Thus, it was established that the plane exploded before it caught fire. This evidence eliminated a popular suspicion of sabotage.

The investigators burned metal comparable to that of the wrecked plane until the metal resembled actual wreckage. By correlating the time required for burning to occur and principles of elementary physics, they established that the plane was flying at approximately 27,000 feet when it exploded.

Having determined the primary sequence of events, the investigators had to find out exactly where the plane exploded. The R.A.E. experts made exact replicas of the Comets, and tied strings of varying lengths to each component of the plane. Then they launched the models from a roof, and as the strings tightened, the plane disintegrated in a definite order, producing a definite wreckage pattern. By changing the lengths of the strings a variation of wreckage patterns were obtained, until one model finally had a wreckage pattern very similar to the wreckage pattern of the real plane. As a result of wreckage pattern analysis the general area of explosion could be plotted. Thus, the R.A.E. established that the failure was somewhere in the forward cabin.

R.A.E. Tests For Metal Fatigue

The investigators found a series of long parallel scratches on the port wing's surface that extended about two-thirds of the wing's length. A piece of fuselage with ragged edges matching the scratches was found, and thus, the R.A.E. was able to establish that the forward cabin was blown out with a tremendous force. This force had to be great enough to blow the piece of fuselage along the wing about twenty-five feet before it was swept away by the high velocity slip-stream.



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Wreckage around ADF windows on top of Comet fuselage where failure originated in the G-ALYP.

A director at R. A. E. thought that the cabin could have failed because of metal fatigue. A failure of this type seemed to be a very remote possibility because the planes were only three years old at the time of the accidents. Nevertheless, a unique test was run to either prove or disprove the theory.

An entire Comet fuselage was submerged in a huge water-filled tank. The wings protruded through leakproof rubber seals in the tank's sides. The water pressure was increased inside the cabin until it represented the difference between the cabin pressure and the atmospheric pressure at high altitudes. To simulate exterior flight loads such as gusts, hydraulic jacks applied oscillatory forces to the wings. These pressures and oscillations were continued until the plane finally failed.

The results of this test showed that there was a tendency towards metal weaknesses near the windows. These weaknesses were caused by high stress concentrations around some of the rivet holes. In the test, the stress concentrations around one hole became greater than the ultimate strength of the metal skin, and a fatigue crack began. The skin became so over-stressed by fluctuating high stress concentrations and by the cabin pressure, that it finally gave way, resulting in an eight foot gash in the cabin. Because of the high cabin pressure, the gash caused an instantaneous decompression, and an explosion. It was such a stress concentration as this that caused the failure of the two Comets in actual flight.

A pressurized model, complete with seats and passengers, was burst in the estimated failure area of the full size plane. It was found that all of the passengers were thrown first forward, then upward, and finally out of the hole caused by the explosion. As the passengers were lifted upwards, they hit their heads on the cabin roof. The time elapsed for this experiment was one third of one second. This explained the reasons for the lung decompressions and skull fractures of most of the victims.

From all of the evidence furnished, it was established that there had been a weak spot in the fuselage over the wings, and a crack had developed, resulting in an explosion. A minute examination of the recovered wreckage pin-pointed a fatigue crack near a rivet hole at the back of the navigators window. Further examination also yielded the direction of the failure and the resulting gashes.

The final conclusions of the R.A.E. were accepted by the Court of Inquiry, and the case was closed. Although apparently adequate design precautions had been taken, the Comet fuselage had failed due to metal fatigue. Why?

Aircraft designers, have long been aware that metal fatigue could cause disaster. They have designed a more than adequate safety factor into their products. They have con-

ducted tests on different aircraft components until every part of a plane was believed to be capable of withstanding the stresses to which it would be subjected. There had been a few plane failures due to metal fatigue, but these failures were relatively insignificant. Few people were injured and causes such as engine vibrations and human error could be found.

Jet Flight Poses Design Problems

In designing the Comet series, the designing engineers relied upon well established methods that were used by almost all aircraft designers. They realized, however, that they were going outside the range of previous experience, and they decided to test every part of the cabin structure. They wanted to be sure that their basic design was sound, and also to investigate the effect of extreme flight conditions on the large number of materials to be used.

The difference between internal and external cabin pressure at the Comet cruising altitude was about 50 per cent greater than that encountered in existing normal flight operations. There was also a greater difference between internal and external temperatures than for low altitude planes. Therefore, special attention was given to the structural soundness of the pressure cabin. It was realized that testing alone was not adequate. In a test, all of the prevailing conditions are not accounted for, and many others are idealized. Hence, the test results had to be combined with calculations based on fundamental knowledge. The designers were aware of the accident potential of doors and windows subjected to internal - external pressure increments of 8 1/4 pounds per square inch. In addition to being a possible crash cause, faulty doors and windows could cause passenger death due to the effects of rapid decompression. Thus the Comets were designed for and tested to pressures much in excess of the safety requirements of any government.

Gusts Are Fatigue Source

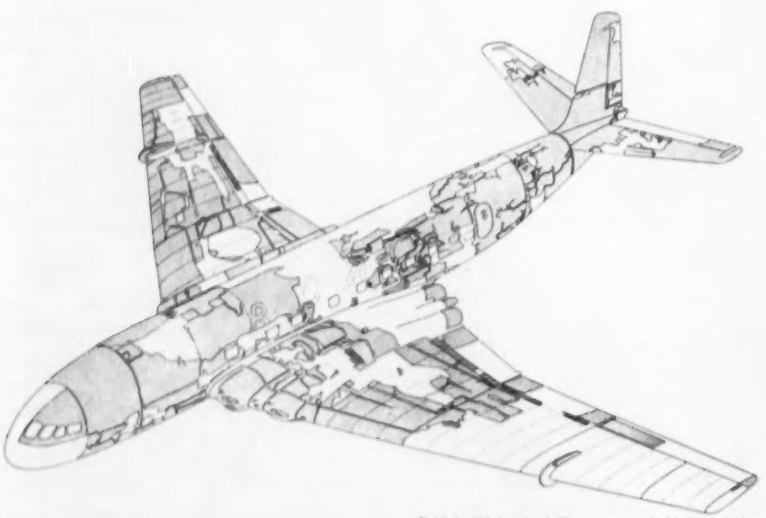
Simultaneous with the cabin tests were tests on all other components of the aircraft. Designers had found, through experience, that the life of the basic structure of an air frame was not unlimited. (This was later shown in the tank tests.) They knew that atmospheric turbulence or gusts had produced unexpected and early failure of some transports. Such gusts cause a rapid increase and decrease in the airflow velocity over an air frame skin, exerting an added force on the air frame. The results of R.A.E. experiments have shown that for every gust of 25 feet per second or over, there are one hundred gusts of 10 feet per second, and that the severity of these gusts depends upon the altitude. In developing a relationship between the hours which a plane flies and the number of gusts it encounters, the R.A.E. found that although in a normal two and one half hour flight only twelve minutes is spent below 4,000 feet, two-thirds of the gust stresses are encountered in the 12 minute period.

Gusts particularly affect the fatigue life of metal in aircraft wings. The problem lies in calculating the internal stress, "S," that results from gusts and extra loads. Although "S" can be found quite accurately on well machined and polished laboratory test pieces, the quantity becomes more elusive in normal aircraft components .The lab data only tells us how good the metal ultimately is.

The actual stress at the most probable position of failure is not necessarily the designed stress average. Because of sharp corners, notches, and other stress raisers, the point of failure will have stress concentrations above the designed average, and may not be the suspected spot at all. In the field all of these calculations are very difficult to obtain.

The most puzzling problem of metal fatigue is not the properties of the failure, but the explanation of these properties. When a metal becomes fatigued, it does not "get tired and quit." Rather, a crack spreads, usually starting from a localized area of high stress concentration, or from some small weakness in the metal itself. This crack may spread until a complete fracture occurs.

Fatigue failure is accentuated by localized stress and structural weaknesses. Holes, notches, and sharp corners cause regions of greater than average stress. These holes, notches, and sharp corners have little bearing upon the static strength of metal, but with oscillatory loads they become vital factors.



British Ministry of Transport and Civil Aviation

Diagram showing amount of wreckage recovered for G-ALYP Comet crash investigations.

Hall Presents Fatigue Theory

Up until recently no acceptable theory explaining the metallurgical process of fatigue failure has been formulated. Sir Arnold A. Hall of the R.A.E. has proposed a theory developed from recent metal tests. Hall's theory is only tentative.

Metals are known to be of a crystalline structure. Under repeated loading within the elastic limit, slip occurs in the crystals of the metals.

This slip is similar to the slip of the crystals when a static stress over the elastic limit causes plastic flow.

It has been observed that a number of metallurgical changes take place in aluminum alloys before fatigue cracking occurs. One of these changes is the "squeezing out" or exudation of thin metallic ribbon from the crystal surfaces. A crevice is left in the surface of the metal, which subsequently may grow catastrophically.

It is well known that in aluminum alloys (used in aircraft skins) high temperatures promote the precipitation of the alloying atoms, leaving a soft matrix in which particles of the precipitate are embedded.

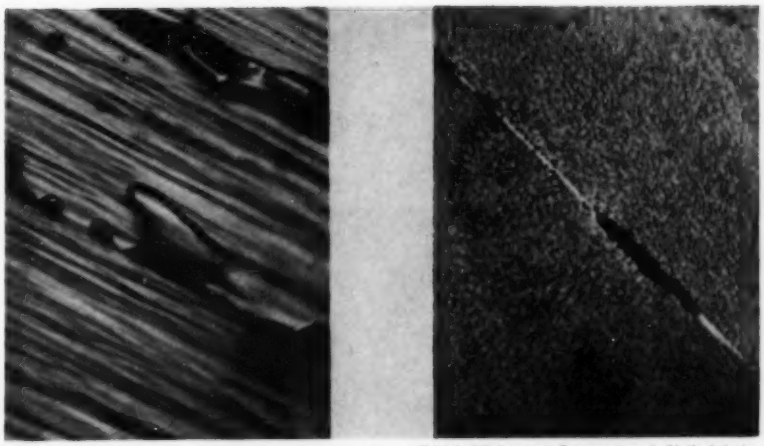
An explanation of the exudation phenomenon started by oscillatory loading is that slip in the crystalline structure causes localized high temperatures. These high temperatures cause precipitation of the alloying atoms, and thus the soft matrix is formed. The soft regions are squeezed out (extruded) by the alternating action of the stresses, and a crevice is formed. Stress concentrations continue the process, and the crevice soon becomes a fatigue crack.

Accidents Focus Design Trends

Metal fatigue in flight requires improvements in basic aircraft design and manufacture. Designers of future air frames must lengthen fatigue life and minimize the catastrophic effects of failure. Also, air frame designers must avoid sharp corners (such as square windows) which produce high stress concentrations. In manufacturing, human errors must be avoided entirely, and manufacturing cracks and dents must be stopped. Even a hammer blow will cause an area of high stress concentration.

The exhaustive Comet crash investigations, and the resulting emphasis upon greater research in aviation metallurgy, are typical of the step by step progress that marks the history of powered flight. The increased performance and complexity of modern jet airplanes means greater expenditure of money and man hours to solve design problems that have never before been significant. The Comet, in its pioneering role in the field of jet-powered commercial air transport, proved that standard tests and design methods were not enough. The impact of high speed flight problems, tragically pinpointed by the Comet crashes, illustrated the need for sure answers and reliable data on phenomena that have until now been in the realm of engineering unknowns. Failure to adequately penetrate the unknowns of high speeds at high altitudes, not basically inferior metals and designers, was the true cause of the crashes.

The jet transport era has begun. However, only through a persistent attempt to bridge existing gaps in engineering knowledge, and a courageous effort to unceasingly translate drawing board improvements into tangible airplane performance, will the aviation industry make that era have lasting benefit for mankind.



—British Ministry of Transport and Civil Aviation

Phenomena occuring during metal fatigue:
a. Exudation between slip bands. (aluminum, 4% copper.)
b. Crack progressing along region weakened by exudation.

AN INVITATION TO THE ALUMNI

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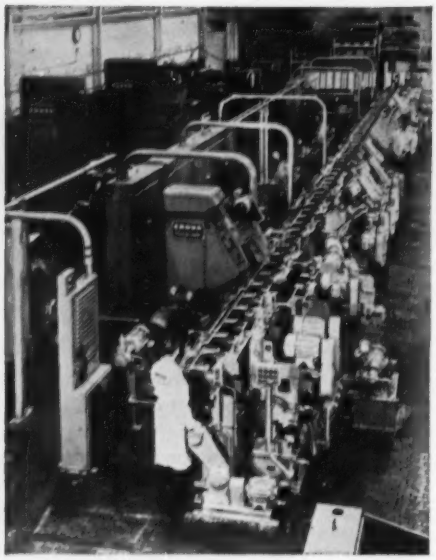
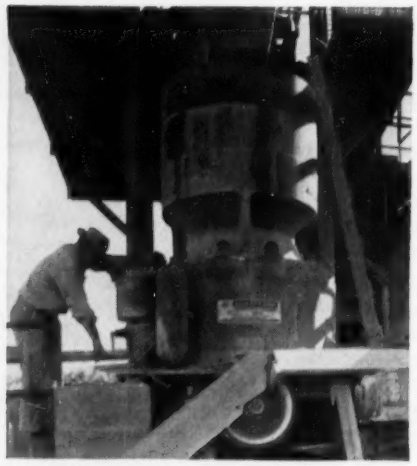


MANUFACTURING — There are 51 Allis-Chalmers motors in this lineup of machine tools designed for high automobile production.



CONSTRUCTION—Crushers like these from Allis-Chalmers process the enormous quantities of aggregate for the booming construction industry.

THERE IS much talk today about growth companies. Allis-Chalmers is one of them, supplying machinery for three basic industries—manufacturing, construction and power.

Therein lies an opportunity for you, since Allis-Chalmers builds many types of equipment.

. . . for a manufacturing industry that must increase output $3.5 billions by this time next year.

. . . for the construction industry that is destined to spend many billions of dollars on highways in the next ten years.

. . . for the electric power industry that will double its capacity by 1956.

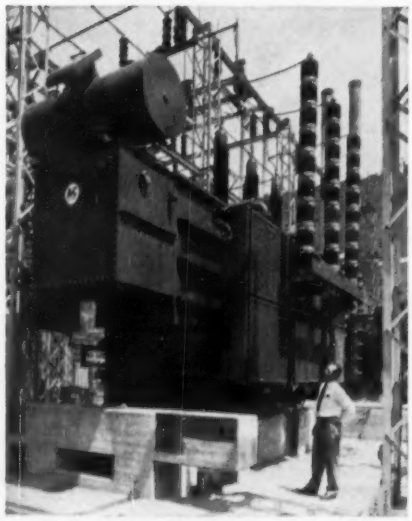
Here's what Allis-Chalmers offers to Young Engineers:

A graduate training course that has been a model for industry since 1904. You have access to many fields of engineering: Electric power, hydraulics, atomic energy, ore processing.

There are many *kinds* of work to try: Design engineering, application, research, manufacturing, sales. Over 90 training stations are available with expert guidance when you want it. Your future is as big as your ability can make it.

Or, if you have decided your field of interest and are well qualified, opportunities exist for direct assignments on our engineering staff.

In any case—learn more about Allis-Chalmers. Ask the A-C manager in your territory, or write direct to Allis-Chalmers, Graduate Training Section, Milwaukee 1, Wisconsin.



POWER GENERATION—Allis-Chalmers is helping meet growing power demand with equipment such as this 150,000 kva transformer.

A-4684 **ALLIS-CHALMERS** Plants and Sales Offices all over the World

Gas Turbine Project to Add 1,700 Jobs
Allison Planning $75 Million Plant Expansion Here
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$75 Million Allison Expansion
Today in Business— Allison's Adds To Prosperity
G. M. Allison Unit to Expand
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1700 New Jobs Scheduled
$75 MILLION ALLISON EXPANSION PLANNED
New Allison Plant to Bring Huge Benefits
Impact on City Will Be Widespread
Allison Plans $75 Million Plant Expansion To Make City World Air Power Center
GM Backs Allison Future By $75,000,000 Program
Allison Expansion Means Huge Benefits
City Will Be World's Center of Air Power
New Plant to Bring City Huge Benefits
Allison Research Gets $75 Million

Long-Range Development Program Provides for New Engineering Test and Research Facilities

● Allison's $75 million expansion program in ENGINEERING, RESEARCH and DEVELOPMENT facilities creates the need for a 40 per cent increase in our engineering staff.

Completion of the five-year program—financed by General Motors—will give Allison, and Indianapolis, one of the world's most complete, best equipped, centers for the development of new, high performance turbo-prop and turbo-jet aircraft engines for both military and commercial use.

As General Motors President Harlow H. Curtice said in the announcement, "Engines in production today cannot meet the requirements of the aircraft of tomorrow where ability to operate at supersonic speeds, and very high altitudes, will continue to be demanded from engine builders . . . To design and build engines with such advanced performance, test facilities are required which go far beyond the capabilities of equipment in existence today. In recognition of this need, General Motors will add extensive high performance test facilities to those already established and in operation at the Allison Division."

Already a recognized leader in the design, development and production of turbo-jet and turbo-prop engines, Allison NOW is in a position to offer even greater opportunities to the technically-trained, well-qualified, young graduate who is interested in building his engineering career with a pace setter in the field.

Whether you're still in school, or graduating this year, we'd like to tell you more about your engineering future at Allison. Write to:

R. G. GREENWOOD, Engineering College Contact
ALLISON DIVISION, General Motors Corporation
Indianapolis 6, Indiana.

YOU FURNISH THE PRINT, WE'LL FURNISH THE PART

TIN PLATE MILL ROLLS, COVERED WITH SYNTHANE LAMINATED PLASTICS, LAST 3 TO 5 TIMES LONGER, CUT DOWN TIME, IMPROVE PRODUCTION

The hundreds of rolls guiding steel plate through pickling, tin-plating and polishing operations at speeds up to 4100 feet per minute take a terrific beating from moisture, acid, sharp edges. Rubber-coated rolls sometimes last but a week. And tiny bits of abraded rubber prevent the deposition of the tin plate, mar the surface. Then Synthane laminated plastic covers were applied directly to the rolls.

What a difference! The hard Synthane surface does not become imbedded with foreign particles. Synthane is anti-static and non-magnetic, doesn't attract metal chips which could scratch the surface.

Synthane is also chemical-resistant; plating acids have little effect upon it, and being an electrical insulator, Synthane does not short the electroplating currents.

The net result is a 3 to 5 times longer life for Synthane-covered rolls, far less downtime; less maintenance and higher production rates. Look into Synthane's combination of properties for your product or application. Write for booklet of Synthane sheets, rods, tubes and fabricating service.

SYNTHANE CORPORATION, 13 River Road, Oaks, Pa.

Please send me more information about the combination of Synthane properties.

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LAMINATED PLASTICS

SYNTHANE CORPORATION • OAKS, PENNSYLVANIA

SKY HOOK . . .

Here is a hook for a hoist—mankind's sinew-sparing servant . . . as industrially indispensable as its load-lifting applications are limitless.

Hoists lift steel beams for buildings and bridges, raise and lower drills and casing for deep-driven oil wells, lift a bucket of cold water from a country well or a ladle of molten metal in a mill . . . lighten load-lifting chores for machinists and miners, loggers and longshoremen, farmers and factory workers.

HOW MANY KINDS?

Consider the many kinds of hoists in use today . . . reeved with rope, cable, chain . . . powered pneumatically, manually, electrically . . . engineered with gears, pulleys, pistons, ratchets.

Think how many millions of plans, sketches, models and mock-ups have contributed to their evolution. The eyes of a myriad of inventors, engineers and draftsmen have appraised them. The hands of countless pattern-makers, tool and die makers, machinists and other craftsmen have shaped them.

Pulling together is a work method uniquely American. And, America can work like that because it has an all-seeing, all-hearing and reporting Inter-Communications System.

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Complete communication is the function and contribution of the American business press . . . the industrial, trade, business and professional publications that are edited to meet the needs of men in business, science and industry.

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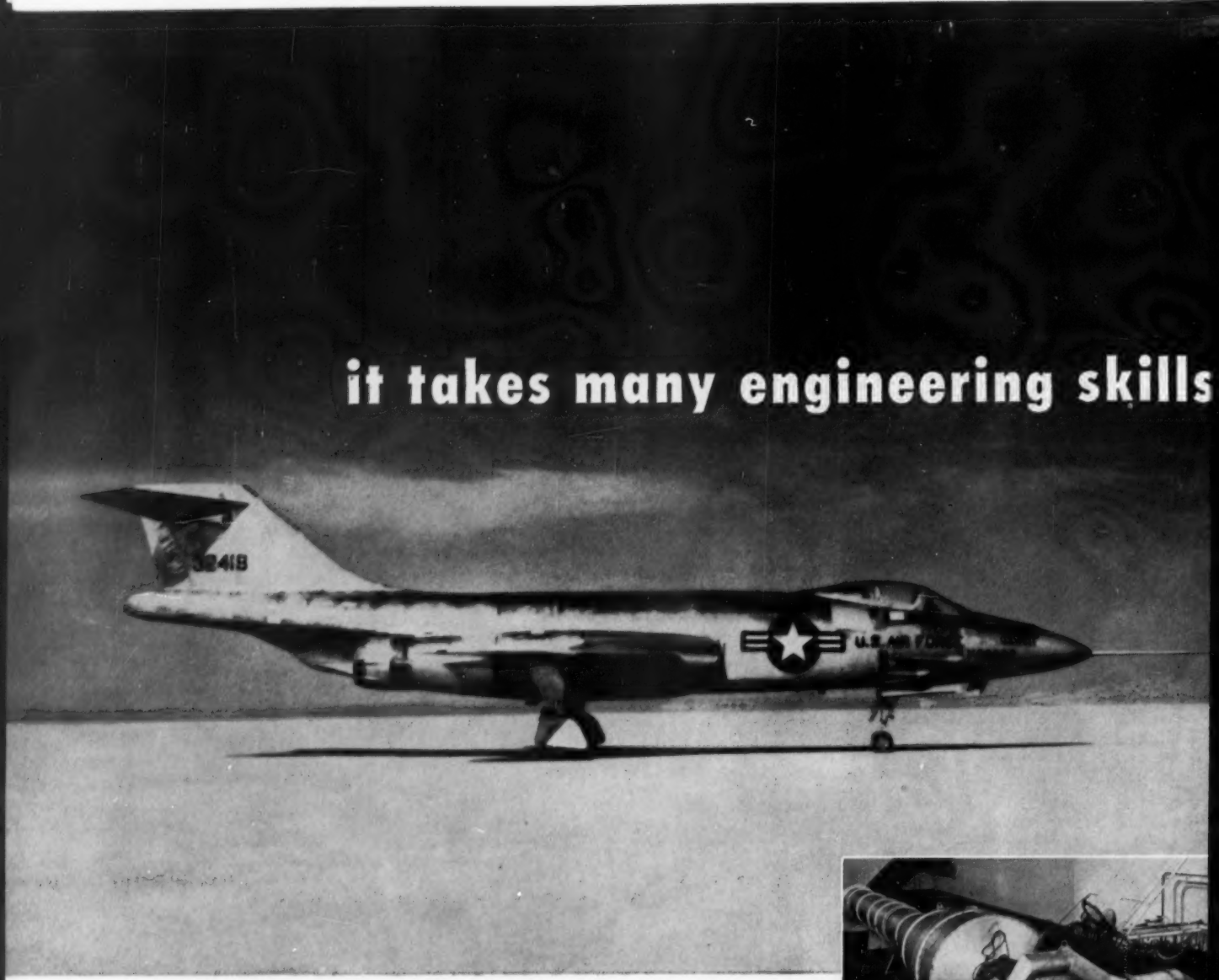
it takes many engineering skills



McDonnell "Voodoo", *the most powerful jet fighter ever built in America.*

J-57 POWERED AIRCRAFT

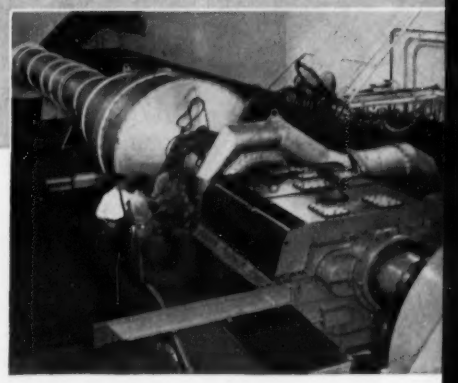
MILITARY

F-100	F8U
F-101	A3D
F-102	B-52
F4D	KC-135

COMMERCIAL

Boeing 707

Douglas DC-8



MECHANICAL ENGINEERS are concerned with many phases including experimental testing and development, mechanical design, stress and vibration analysis, combustion research, heat transfer and nuclear reactor development.

AERONAUTICAL ENGINEERS work on innumerable internal and external airflow problems concerned with design, development and testing of aircraft powerplants. Some who specialize in analytical engineering forecast engine-airplane combinations a decade in advance of design.

ELECTRICAL ENGINEERS directly contribute their specialized skills to the analysis and development of controls, systems and special instrumentation. An example is the "Plottomat" which automatically integrates and plots pressures, temperatures and air angles in performance testing.

ls to create the top aircraft engines

An aircraft powerplant is such a complex machine
that its design and development
require the greatest variety of engineering skills.
Pratt & Whitney Aircraft's engineering team
has consistently produced
the world's best aircraft engines.

The best planes are always designed
around the best engines. Eight of the most
important new military planes are powered by
Pratt & Whitney Aircraft J-57 turbojets.
The first two jet transports in the United States
will use J-57s. Further, no less than
76 percent of the world's commercial air transports
are powered by other Pratt & Whitney Aircraft powerplants.

Such an enviable record can only be built
on a policy which encourages, recognizes and
rewards individual engineering achievement.

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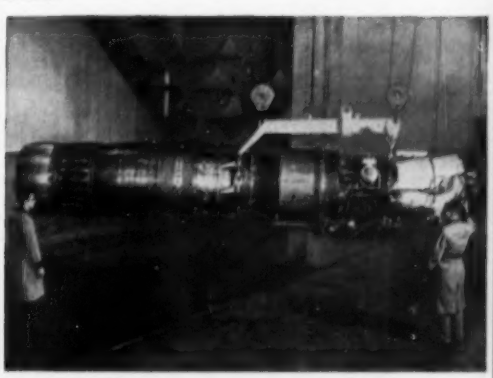
World's foremost designer and builder of aircraft engines

CHEMICAL ENGINEERS, too, play an important role. They investigate the chemical aspects of heat-producing and heat-transferring materials. This includes the determination of phase and equilibrium diagrams and extensive analytical studies.

METALLURGISTS investigate and develop high temperature materials to provide greater strength at elevated temperatures and higher strength-weight ratios. Development of superior materials with greater corrosion resistance is of major importance, especially in nuclear reactors.



WORLD'S MOST POWERFUL production aircraft engine. This J-57 turbojet is in the 10,000-pound thrust class with considerably more power with afterburner.

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William M. Leonard

"The objects of this Society are to promote the welfare of the College of Engineering at Cornell University, its graduates, and former students and to establish closer relationship between the college and the alumni."

When I attended Cornell the word "opportunity" used to put my teeth on edge. By the time I reached college it had already been with me for a long time. Ever since grammar school I had been subjected to noble and inspiring lectures on the "opportunity" which was ahead of us. I was pretty tired of hearing about it.

I know you feel the same way. However, there is an old tradition that any of us with gray in our hair may speak of "opportunity" whenever we find ourselves face to face with a captive audience of young people. It is one of the compensations that go with age. Listening to us oldsters is one of the penalties of youth.

Seriously, there is something new to say on the subject of opportunity—something which is encouraging and disturbing. Opportunity has always been a two-sided thing. First of all, a chance must be presented that calls for a man of initiative training and courage. And then, the man with those qualifications must be on deck to make use of the chance.

At least that is the way it used to be, but let us look at the present picture. The American industrial structure is on the verge of a great and glorious break through. Ever since the Revolutionary War, when Eli Whitney introduced the principle of standardization into manufacturing to step up production, the advance of mechanism has accelerated with each decade. Now we find ourselves making the transition from a push-button age into one of automation. You might say we are about to step from the ingenious to the fabulous. What is more to the point, we Americans are heading into an age of qualified engineers. In view of this, any normal person should expect the young men of America to be beating on the doors of the engineering schools. You would think that those who succeeded in gaining admittance would devote the full time prescribed to gaining a professional degree.

Instead, it is the colleges and their alumni who have to beat the woods for high-grade students and try to tell young men that the calculus is quite as important as Plato and offers far more in the way of rewards. Moreover, a large proportion of the young men who get to engineering schools pack-up and leave for home at the end of two years, even though they must realize that by so doing they are sentencing themselves to second-class careers.

Americans have solved many great political, social and industrial problems in the history of the republic. Right now they face a problem that must also be solved for the good of the country. Based as it is on industrial strength, America must maintain and increase its living standards in order to keep its world leadership. Without engineers, and good engineers at that, this will be impossible.

We simply must find a way to induce the up-coming generation of young people to grasp the tremendous opportunity that is theirs in the field of engineering.

Ironically, the American tradition of opportunity (opportunity = enterprise + freedom) this tradition is partly responsible for the fact that today we are falling behind Soviet Russia in the output of qualified engineers. The commissars have a simple and effective system—they tap the bright students and make them engineers whether those individuals like the idea or not. Personnel reports indicate that some of this new crop of Russian engineers measures up well in quality.

In the United States a young person has a free choice of career—none of us would wish it otherwise. But all too often the capable young man chooses to pass up the opportunity of a challenging, exciting, and rewarding career, one that is vital to the security and economic welfare of his country and to the happiness and well being of his countrymen.

W. M. LEONARD

ALUMNI ENGINEERS

The Board of Directors of The Lincoln Electric Company has announced the appointment of **L. K. Stringham, E.E. '33,** as Vice President in charge of Engineering. He has been Chief Engineer for the Company since 1951.

Stringham joined the Lincoln Engineering Department immediately following his graduation from Cornell University. His experience in the department he now heads has included all phases of engineering: experimental research, product development, testing and application. He has designed welding machines, electrodes, and fluxes for both manual and automatic welding. Of particular importance was his pioneering work in the development of agglomerated fluxes for the Hilden arc welding process and their application in industry with automatic and semi-automatic welding equipment.

L. K. Stringham

Prior to his appointment as Chief Engineer in 1951, Stringham was Director of Welding Development where he was responsible for the development of applications for welding processes and equipment. He is a member of the Board of Directors of the Company and a member of the AWS-ASTM Committee for Filler Metal. He is a Fellow in the American Institute of Electrical Engineers, a member of the A.I.E.E. Electric Welding Committee, a member of the American Welding Society, and the electrical honorary society, Eta Kappa Nu. He lives at 2700 Endicott Road, Shaker Heights, Ohio.

C. Harold Berry, ME '12, professor of mechanical engineering at Harvard University, will retire this summer after twenty-seven years with the Harvard faculty. From 1913-18, he was instructor and professor of Heat-Power Engineering at Cornell.

Myron B. Brookfield, ME, '50, 8140 Lahser Road, Bloomfield Hills, Mich., has joined Mechanical Handling Systems, Inc., Detroit, as a sales engineering trainee. He returned last December from a nine-month tour of South and East Africa.

Allan H. Rogers, ME '24, is superintendent of public works, Garden City. In 1953 he was president of of the New York Section of American Water Works Association. He is a member of the Institute of Traffic Engineers and the Garden City Planning Commission. A member of the Cornell Clubs of New York and Nassau County, he lives at 101 Eleventh Street, Garden City.

Ferdinand W. Dohring, ME '24, is vice-president and director of the Elliott Co., Jeannette ,Pa. He is also director of the First Jeannette Bank and Trust Co., and president of the Greensburg Country Club, Greensburg, Pa.

Harman Knauss, ME '24, is director of Mutual Life Insurance Co. of New York. He is a director of National Records Management Council, a planning council member of the American Management Association, a director of the Katonah Village Improvement Society, and a trustee of the Katonah Library.

Henry B. Wilkinson, EE '24, is president and general manager of Ingham & Wilkinson Ltd., located in Hamilton, Bermuda. He is a director of the Bermuda Electric Light, Power and Traction Company, the Bank of N.T. Butterfield & Son Ltd., and Island Pictures, Ltd.

C. Douglas Repp, EE '48, is a project engineer in the engineering department of Pennsylvania Power and Light Co., Allentown.

Frederick Kelly Wing, CE '90, died on January 27. He had his own civil engineering firm in Buffalo, specializing in waterworks, filtration, and sewage disposal. From 1938-42 he was city engineer of Buffalo. Prior to that, from 1935-37, he was Chief Engineer of Niagara Frontier Planning Board.

Victor M. Cortina, '23, is assistant general manager and staff engineer of West Indies Sugar Corp. His address is Ingenio Consuelo, San Pedro de Macoris, Dominican Republic, W. I.

A. H. Jackson, ME, former sales manager of the Tower Department, Equipment Division of the Blaw-Knox Company, Pittsburgh, has been promoted to general manager of the division's newly established Engineering and Development Department.

In this post he will co-ordinate engineering, research and development of the six major product lines manufactured by the division, including towers, steel plants, road construction equipment, clamshell

A. H. Jackson

buckets, and forms.

Mr. Jackson, a native of Pittsburgh, has been with the company for 28 years.

Charles H. Adler, CE '24, is district manager of the Central Hudson Gas & Electric Corp. in the Beacon district. He is a member of the Cornell Clubs of Dutchess County and New York and participated in the Greater Cornell Fund drive in 1950 as an area chairman. He has served prominently on the Beacon Chamber of Commerce, the Dutchess County Red Cross, and is a member of the Kiwanis Club of Beacon, of which he was president in 1950. He has been a director of the Kiwanis Club since 1947.

William H. Kreamer, ME '40, has been promoted from Assistant Chief Plant Engineer to Chief Plant Engineer of the Roanoke plant of the American Viscose Corp. He has been with Avisco since his graduation from Cornell. He is a member of the American Welding Society, the Virginia State Chamber of Commerce, and is Chairman of the Virginia Section of ASME and President of the Southwest Virginia Engineers. This April he was elected an honorary member of the Virginia Tech Epsilon Chapter of Pi Tau Sigma. Since 1954, he has been a Registered Mechanical Engineer in the State of Virginia.

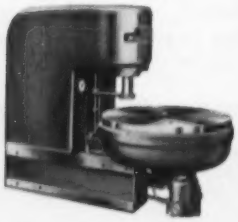
William H. Kreamer

Keeping toys rolling

with **DENISON** hydraulic equipment

KEEPING toys rolling presents production problems. Like trimming the excess rubber from molded rubber wheels. Until Denison Multipress® got on the job, this was a slow, costly procedure.

The job took several operations and a lot of loading and unloading time. Multipress does it the easy, oil-hydraulic way. One smooth stroke of the hydraulic press ram trims flash neat and close; no need for buffing operations. A Denison Index Table automatically carries wheels under the ram and an air blast ejects them. Output: Up to 2400 wheels an hour.



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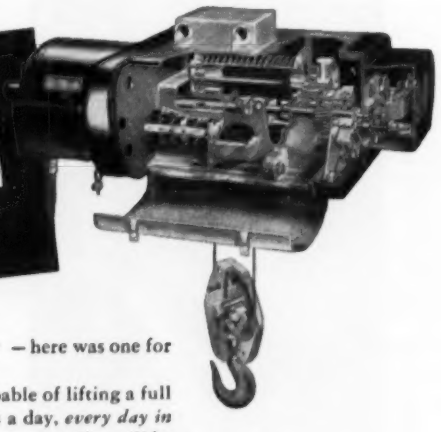

Talk about engineering "brainteasers — here was one for the books!

Design a one-ton capacity hoist capable of lifting a full load thirty feet a minute, three shifts a day, *every day in the year.* Make certain that the power you require will be concentrated on lifting and not shared in overcoming friction. Be sure, too, to provide for smooth, steady performance with a minimum of maintenance. This was the problem facing Manning, Maxwell & Moore's team of electric hoist designers. They solved a big part of it by installing dependable, Fafnir Ball Bearings at every possible source of friction — on the rope drum, trolley assembly, gear shafts, and other critical turning points.

The ready availability of precision anti-friction ball bearings for all types of industrial machinery is but one of many reasons why more and more engineers specify Fafnir for every bearing need. The Fafnir Bearing Company, New Britain, Connecticut.

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A motion-sound picture dramatizing high points in the manufacture and use of Fafnir Ball Bearings is available to engineering classes. Write for details.

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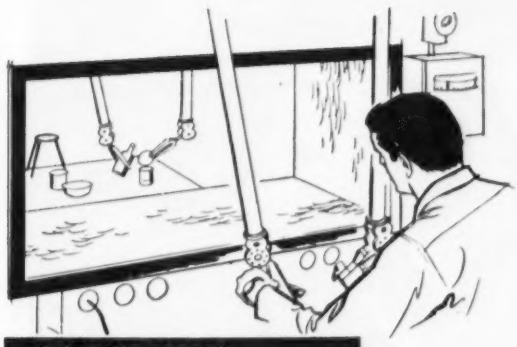

IN ATOMIC ENERGY...

"I'm Class of '52, with a B.S. in chemistry. I wanted to do research in the atomic energy field, so I went to work at Oak Ridge National Laboratory, which Union Carbide Nuclear Company operates for the AEC. After two promotions I'm an Associate Chemist, doing research in special materials important to the atomic energy program."

IN CHEMICAL ADSORBENTS...

"I'm a chemical engineer, Class of '51. Two years after I joined Linde Air Products Company I was in charge of a group of engineers and technicians synthesizing Molecular Sieve adsorbents. I recently transferred to a Development group exploring applications of these new adsorbents, and have many opportunities to help LINDE customers with their problems."

IN AUTOMATIC PRODUCTION...

"I'm a mechanical engineer, Class of '50. I went to work for National Carbon Company and after a brief orientation program, helped in the development of several machines for the automatic production of dry batteries, including a new injection molding process. Now I'm administrative assistant to the head of the Machine Development Department."

IN PUBLICITY...

"In '52, right after I received my M.A. in Journalism, I went to work in the Chicago Office of Union Carbide's General Publicity Department. In August, '54, I was transferred to the General Offices in New York, and six months later was promoted to Supervisor in the Publicity Department's plant-community relations and employee communications group."

THEY ARE KEY MEN WITH A FUTURE...

If you are interested in a future in production, development, research, engineering, or technical sales, check the opportunities with any Division of Union Carbide. Get in touch with your college placement officer, or write directly to:

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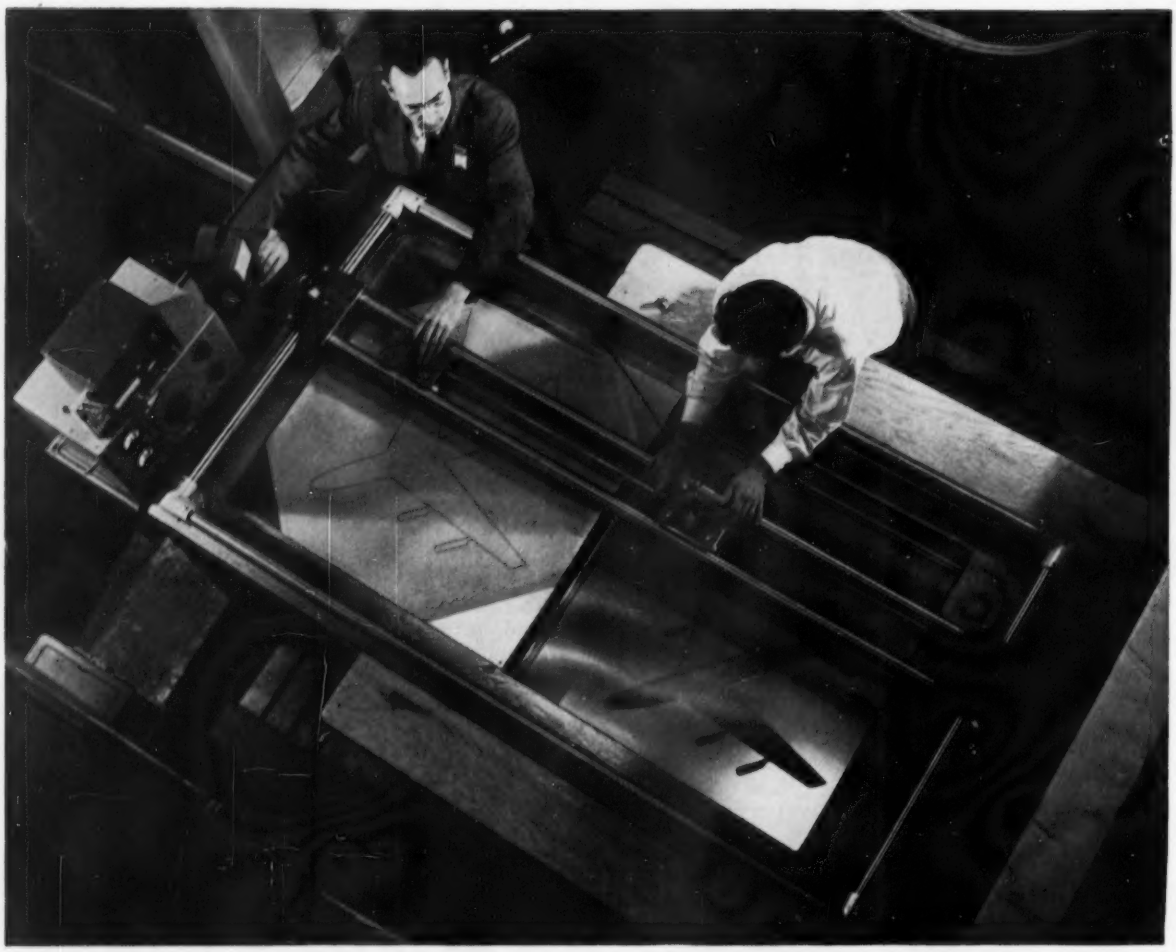

Boeing engineers are kept free for creative assignments

Thanks to draftsmen and engineering aides, Boeing engineers are free to handle stimulating projects like this: determining antenna properties in an electrolytic tank. Results taken with the three-dimensional plotter will influence the configuration of "years-ahead" Boeing airplanes and guided missiles now in the design stage.

At Boeing, engineers have the same relationship to draftsmen and engineering aides that doctors have to technicians and laboratory assistants. The abilities of a Boeing engineer are fully utilized: in investigating heat, compressibility and other problems of supersonic flight; in jet, ram-jet, rocket and nuclear power; in electronic control of missiles, and much more—calling for a variety of skills in all the engineering fields.

This electrolytic tank is one example of the superb equipment at Boeing engineers' disposal. Other facilities include the world's most versatile privately owned wind tunnel, a new tunnel under construction, capable of velocities up to Mach 4, the latest electronic computers, and splendidly equipped laboratory and test equipment in the new multi-million-dollar Flight Test Center.

Achievements of each Boeing engineer are recognized by regular, individual merit reviews, and by promotions from within the organization. Boeing offers exceptional career stability and growth: this soundly expanding company now employs more than twice as many engineers as at the peak of World War II.

Of technical graduates at Boeing, 30% are mechanical engineers, 24% electrical, 19% aeronautical and 9% civil engineers. The remainder are chemical, metallurgical, and other kinds of engineers, and physicists and mathematicians with advanced degrees.

In planning for your professional career, look to Boeing for a truly creative job. Begin now to prepare for a place on one of Boeing's engineering teams in design, research or production.

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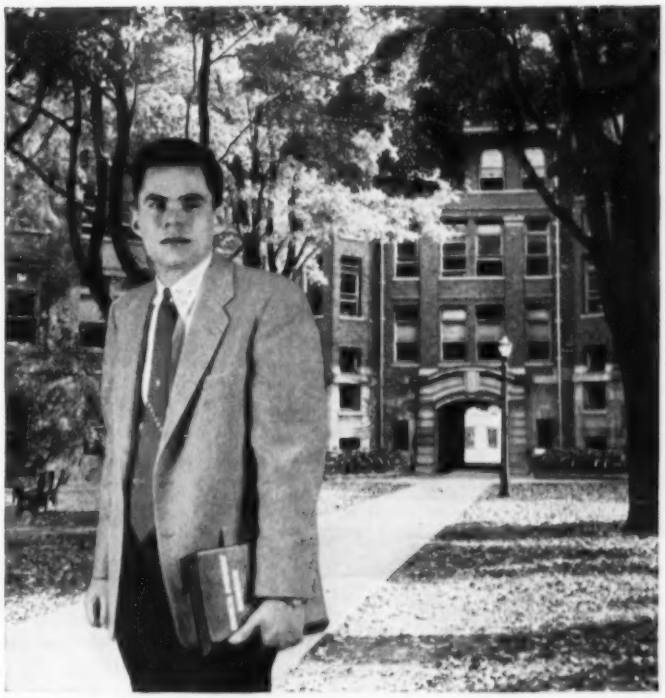
MARTIN
BALTIMORE

Charlie Stickels asks:

Does Du Pont hire graduates who are draft eligible?



CHARLES A. STICKELS is currently working toward his B.S.E. degrees in chemical and metallurgical engineering at the University of Michigan. Mr. Stickels is past Editor-in-Chief of the *Michigan Technic*, vice-president of his student chapter of A.I.Ch.E., and a member of several honorary engineering fraternities. His editorial work has made him especially aware of contemporary employment questions facing engineering graduates.

JOHN OLIVER, also a University of Michigan man, received his B.S. in Mech. Eng. in 1938. Right after graduation, he began working for Du Pont in the Engineering Section of its Belle, W. Va., plant. Following this came an assignment as Departmental Engineer in the Wilmington offices, and today John Oliver is again at Belle—this time as Assistant Plant Manager.

John Oliver answers:

The answer to that is definitely "Yes!", Charlie. We've employed quite a number of college graduates with definite military commitments, sometimes knowing that they could work only a few weeks before reporting for active duty.

The reason is that Du Pont is primarily interested in men on a "long range" basis. The fact that they're temporarily unavailable—for a good reason like military service—isn't any bar to being considered for employment. After working only one day, an employee is guaranteed full re-employment rights—that's the law. But if a man works for Du Pont at least a full year before joining the service, he gets a bonus of two months' salary. If he's entitled to a vacation but doesn't have time to take it before leaving, Du Pont gives him equivalent pay instead.

Even if present employment is impossible, Charlie, we definitely recommend your talking with Du Pont's representatives—and those of other companies, too. The very least you'll gain will be valuable background and some contacts which may be of real benefit to you when you leave military service.

WANT TO KNOW MORE about working with Du Pont? Send for a free copy of "Chemical Engineers at Du Pont," a booklet that tells you about pioneering work being done in chemical engineering—in research, process development, production and sales. Write to E. I. du Pont de Nemours & Co. (Inc.), 2521 Nemours Building, Wilmington, Delaware.

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College News

University Installs "Nuclear Engineering" Option For Undergraduates

Atomic energy will enter the undergraduate engineering curriculum at Cornell University next fall.

Establishment of a "nuclear engineering option," to help meet a growing need for engineers trained in atomic science, was announced by the College of Engineering.

An elective program augmenting Cornell's regular five-year undergraduate engineering course, it will be open to qualified students in the divisions of chemical, civil, electrical, mechanical and metallurgical engineering, and engineering physics.

"We believe engineers will be the most productive in the nuclear field if they are able to apply their particular field of engineering in combination with a sound knowledge of nuclear physics and related technical subjects," Dean S. C. Hollister declared.

The new program will draw mainly on staff and facilities of the university's Departments of Physics and Engineering Physics, Newman Laboratory of Nuclear Studies, and School of Chemical and Metallurgical Engineering. A staff member with nuclear experience will be added to the Department of Engineering Physics to supervise it.

Because Cornell's undergraduate engineering courses cover five years instead of the conventional four, it has been possible to incorporate the new option without lengthening the training period. Nuclear engineering programs at other institutions are being instituted primarily on the graduate level.

Acquisition of a nuclear reactor is under study. Initially, there will be experiments in neutron physics and other fields pertinent to work with actual reactors.

The option will consist of approximately 12 hours of courses and laboratory work in atomic, solid state and nuclear physics; the physics of nuclear reactors; nuclear measurements; advanced heat transfer and diffusion; properties of reactor materials; radiation damage; radiation-induced corrosion and creep; atomic fuels, fuel processing and waste disposal, and biological effects of radiation.

"Cornell recognizes the need to prepare men in this very important new area," said Dr. Lloyd P. Smith, chairman of the Departments of Physics and Engineering Physics. "If the industrial and power companies carry through with the developments that have been projected, there will be an enormous shortage of engineers and physicists with sufficient knowledge of the technology required in the nuclear engineering field."

In planning the new option, the engineering faculty was aided by two of the key figures in industrial atomic progress—Walker L. Cisler, president of Detroit Edison Company and of Atomic Industrial Forum, and J. Carlton Ward, Jr., president of Vitro Corporation. Both are Cornell engineering alumni.

Scholarships Awarded

The Standard Oil Company of California, in appreciation of the quality of its employees who are graduates of Cornell's School of Chemical and Metallurgical Engineering, is granting scholarships for 1955-56 to two students in the school.

The awards are described as graduate scholarships, the company considering the fifth year in Cornell's engineering course as an equivalent of the first year of post-graduate study.

The winners, who will begin their fifth year in chemical enginering next September, are Conrad V. Chester of Roslyn Heights, N. Y., and James R. Sylla of Chicago Heights, Ill. Each will receive $750 and half of his tuition, and the school will receive $750.

In announcing the grant, W. L. Ingraham, chairman of the company's professional personnel committee, wrote, "For some time, our company has noted with interest the quality of training and caliber of students in the chemical engineering school at Cornell, particularly the men in our employ who have graduated from this school."

Mr. Chester is a son of Mr. and Mrs. A. A. Chester of 102 Parkside Drive, Roslyn Heights, and a graduate of Roslyn High School.

Mr. Sylla is a son of Mr. and Mrs. Ben A. Sylla, 169 Country Club Road, Chicago Heights, and a graduate of Bloom Township High School.

Cornell University's two Monsanto Chemical Company Scholarships for the academic year 1955-56 have been awarded to Fred E. Stafford and Martin T. Mace.

Mr. Stafford, son of Mr. and Mrs. Frank H. Stafford of 1424 Longfellow Avenue, Bronx, N. Y., is completing his junior year as a chemistry major in the College of Arts and Sciences. He graduated from the Bronx High School of Science.

Mr. Mace is completing his second year in the five-year course of the School of Mechanical Enginering. He is a son of Mr. and Mrs. A. F. Mace, 68 Elm Street, Newport, Maine, and a graduate of Maine Central Institute.

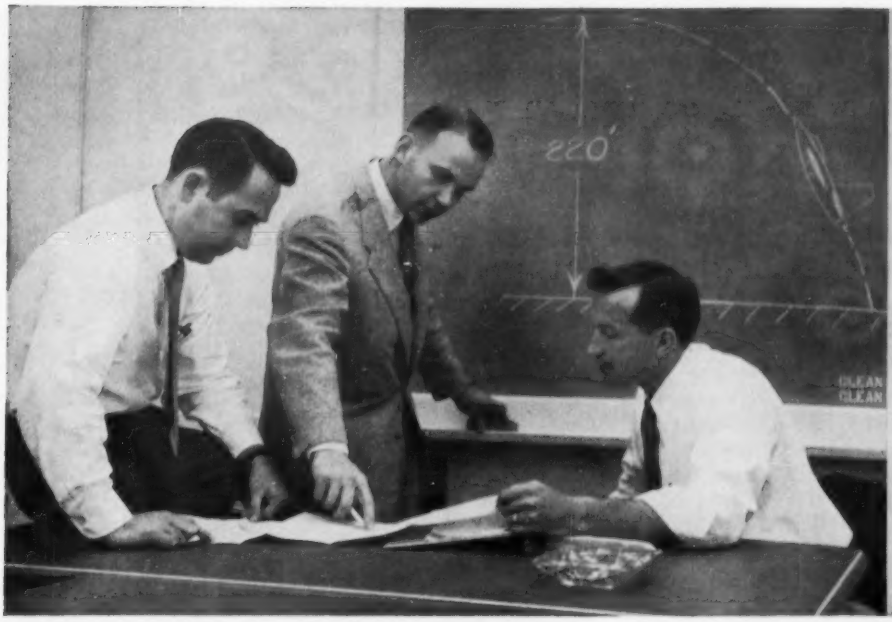
The annual scholarships provide a stipend of $700 to a student in chemistry and one in mechanical engineering.

Summer Astronomy Conference

The Cornell Department of Astronomy was host to a conference of astronomers on April 29-30.

The group included professional astronomers and others interested in teaching or research in this field, from upper New York State and western New England.

Prof. E. E. Salpeter of the Laboratory of Nuclear Studies spoke Friday evening on "The Evolution of the Stars." Prof. R. William Shaw, chairman of the astronomy department, demonstrated equipment and teaching techniques used in intro-



N. T. Avant, aerodynamicist (left), R. R. Heppe, Aerodynamic Department head (center), and C. F. Branson, aerodynamicist, discuss wind tunnel tests to determine transition height of a supersonic superiority fighter.

Hovering to High Speed Flight:

Lockheed Aerodynamics Projects Offer Advanced Problems

Aerodynamics Engineers at Lockheed are working on advanced problems that cover virtually every phase of aircraft. The full scope of their work can be seen in the wide range of aerodynamics problems encountered in Lockheed's diversified development program.

Among the advanced problems are:

1. Determine means of controlling a supersonic vertical rising aircraft through the transition flight stages from horizontal to vertical flight.
2. Determine the dynamic response of supersonic aircraft in high rate rolls by application of five degrees of freedom analysis procedures.
3. Study optimum operating descent procedures to minimize costs on a new turboprop commercial aircraft.
4. Conduct and analyze wind tunnel research on new and radically different external radomes to be carried at high speed by early warning aircraft.
5. Perform generalized aeroelastic analysis combining structural and aerodynamic knowledge to determine optimum lateral control devices for use on very high speed, low load factor aircraft.

These – and many other – significant problems have created new positions for experienced Aerodynamics Engineers and Aerodynamicists in Lockheed's expanding program of diversified development.

You are invited to contact your Placement Officer for a brochure describing life and work at Lockheed in the San Fernando Valley.

Additional information on these problems and data on Lockheed's Aerodynamics Division is available to interested engineers. Address inquiries to R. R. Heppe.

LOCKHEED AIRCRAFT CORPORATION

CALIFORNIA DIVISION BURBANK **CALIFORNIA**

ductory laboratory astronomy, a field in which the Cornell department is a recognized leader.

On Saturday morning the group heard a lecture on "Expanding Hydrogen Regions" by Dr. M. P. Savedoff of the University of Rochester, and visited Cornell's Radio Astronommy Laboratory and Fuertes Observatory.

Summer Engineering Conference

Prof. Norman R. Gay of Sibley School of Mechanical Engineering at Cornell, was selected by the General Electric Company to participate in the 16th Annual G. E. Professors' Conference June 27-July 29.

The conference was designed to give a selected group of engineering professors a close look at industry, study current engineering, manufacturing and marketing practices, to let them observe the industrial utilization of engineering graduates, and to let them work on some specific projects in their particular fields of interest.

The conference was attended by 25 professors from various engineering schools throughout the country.

Cornell Faculty Papers Published

Papers by Prof. Cevdet Z. Erzen of Cornell's School of Civil Engineering have been published in Turkey and the United States.

A highly theoretical paper on the solution for small deflections of rectangular plates with different edge conditions has been published in the Bulletin of the Technical University in Istanbul.

"Lateral Bending of Suspension Bridges," published in the Proceedings of the American Society of Civil Engineers, discusses bridge designs which can best resist the horizontal forces of high wind pressure.

Before coming to Cornell last September, Professor Erzen taught for three years at the University of Connecticut and was associated with Ammann and Whitney, consulting engineers. Professor Erzen is a native of Turkey and received his B.S., M.A. and Ph.D. from the University of Illinois.

New Scholarships

Several scholarships are being added to the 1955-56 program of financial aid to higher education in the United States and Canada by the producing departments of Socony Mobil Oil Company (formerly Socony-Vacuum Oil Company) and its affiliates.

The scholarships, which will number 74 in the next academic year, are in addition to those provided by the Socony Mobil Laboratories. They total $52,750 in amounts ranging from $500 to $750 and are mainly in exploration sciences and various fields of engineering. One fellowship of $3,000 also is planned.

Eleven of the scholarships are at Canadian universities and two are for Canadian scholars at American universities.

The producing departments of the various Socony Mobil companies also offer an "incentive" fellowship for which only employees are eligible.

Socony Mobil's total aid-to-education program will exceed $325,000 for the next school year.

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Engineer's Day, 1955

As the loudspeaker on top of Phillips Hall blared forth it's invitation to the inhabitants of Tompkins County to rush to the fantastic exhibits, our annual Engineer's Day got under way on April 29th.

Down the road a short distance the chemical engineers were doing their bit to educate the masses. A guided tour of Olin Hall included a display by the Sun Oil Company showing its petroleum refining process. In the U. O. lab a column was on display demonstrating the absorption of gases on to the solid packing material. A crisis arose, when a wrong valve was turned and a myriad of hitherto unknown colors appeared in the column. However, as usual, the Chem. E's were equal to the occasion and with the coolness and efficiency that is characteristic of these men, they lost no time in asking their professors what the trouble was. One of the students demonstrated his fifth year project, an improved turbo grid distillation column. An Arts student was quite disappointed when he was told that benzene and not bonded scotch was being collected at the top of the tower.

Over on the other side of the campus, the civil engineers had constructed a model town, complete with modern shopping district, recreational center, improved street plan, and a modern sewage disposal plant. It was very effective in its presentation of the way in which the various phases of civil engineering are applied to a community both in its operation and in its growth and development. On the north end of the quad the mechanical engineers displayed their old Corliss steam engines, alongside a modern V-8 automobile engine, on a dynamometer testing stand. Locomotive and submarine diesel power plants could be seen at the Diesel lab. The Department of Industrial and Engineering Administration offered an exhibit in which a student defeated all challengers in a contest of placing round pegs in a board. Thus they demonstrated that the most efficient methods were a great advantage in speeding up any process, no matter how trivial.

For those fascinated by the newly discovered energies within the nucleus of the atom, the Engineering Physics Department showed its new synchrotron. The EP's also demonstrated a cooling apparatus which was at a temperature of a few degrees above absolute zero. This is even a bit colder than the average Ithaca winter.

The embryo Frank Lloyd Wrights in the school of architecture showed their fifth year projects, designs of future dream houses and well planned residential areas.

The weekend was completed on Sunday May 11, when the Engineer's Banquet was held at the Clinton House. Awards were presented to the winning exhibits, and the engineers went away looking forward to Spring Weekend. A few began brushing up on their heat power equations, realizing with a certain amount of apprehension that only a few weeks away were the inevitable final exams.

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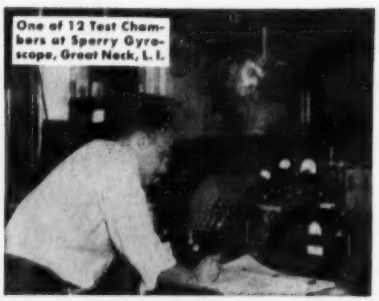
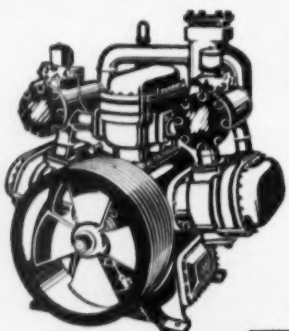

One of 12 Test Chambers at Sperry Gyroscope, Great Neck, L. I.

Then the chances are that Frick engineering and production facilities can serve you.

We specialize in custom-built refrigerating and air conditioning equipment: our engineers, designers, foundrymen and mechanics team up to handle those unique jobs which other manufacturers hesitate to accept.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PROGRESS REPORT

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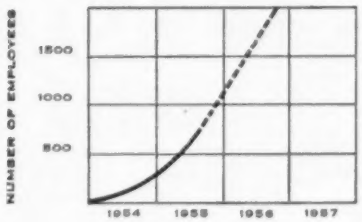

PROJECTS

Our eight current military contracts support a broad range of advanced development work in the fields of modern communications, digital computing and data-processing, fire-control, and guided missiles. This work is supplemented by non-military activities in the fields of operations research, automation, and data-processing.

FINANCES

In 1954, our first full year of operation, we showed a good profit. Of greater importance, however, are the arrangements recently completed with Thompson Products, Inc., our corporate associate, whereby we are assured additional funds up to $20,000,000 to finance our expansion requirements of the next few years, and insure the long-range stability of the company.

RESEARCH AND DEVELOPMENT PERSONNEL

Total population figures, such as those displayed in the curve, tell only a limited story. Personnel quality factors are most important, in our kind of business. We believe we are doing well in this respect. Of the 90 Ph.D.'s, 65 M.S.'s and 75 B.S.'s or B.A.'s who today make up our professional staff, a gratifyingly high percentage are men of broad experience and, occasionally, national reputation in their fields.

FACILITIES

By mid-1956 our Los Angeles facility will consist of seven buildings totalling 300,000 square feet of modern research and development space. Two of the three buildings now complete and occupied are shown at bottom of this page; a fourth and fifth are presently under construction, the others are in the design stage.

MANUFACTURING

We are somewhat ahead of the usual systems development schedule, with some of our projects having arrived at the field and flight-test stages. We are now planning a facility for quantity production of electronic systems. Construction on the initial unit of 160,000 square feet (shown above) is expected to start in late 1955, with manufacturing planned for late 1956.

The Future

Our first year and a half of corporate history encourages us in the belief that our future will be one of expanding productivity. But whether we remain a small company or grow large, we plan not to lose sight of the fact that the continued success of The Ramo-Wooldridge Corporation depends on our maintaining an organizational pattern, a professional environment, and methods of operating the company that are unusually well suited to the very technical, very special needs of modern systems development and manufacturing.

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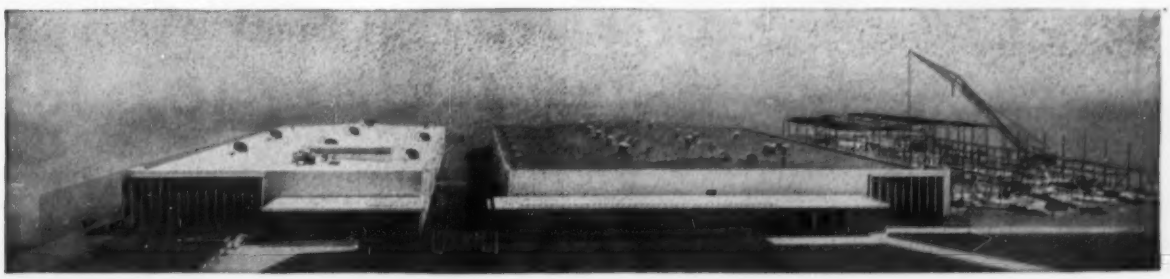

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Technibriefs

Color Television Tape Recorder Developed

A color television program recorded on magnetic tape was transmitted over commercial television network facilities for the first time on May 12, 1955, by the Radio Corporation of America and the National Broadcasting Company.

The tape-recorded telecast, originating with the prototype RCA TV tape recorder installed for field testing at the NBC studios in New York, was transmitted over a closed circuit from New York to St. Paul as part of the dedication ceremonies of the new research center of the Minnesota Mining and Manufacturing Company.

The RCA magnetic tape recording system was demonstrated under laboratory conditions on December 1, 1953, at the David Sarnoff Research Center, the first major step into an era of "electronic photography," in which motion pictures in color or black-and-white will be produced quickly and economically, eliminating most of the time and all of the chemical processing involved in photography.

It was pointed out at that time that RCA's objective in developing such a system was to achieve a swift, economical and efficient means of recording color television programs for storage, playbacks or re-broadcast. A tape recorder capable of performing this function was requested by General Sarnoff in 1951.

The TV magnetic tape recorder is similar in its basic principles to the conventional tape recorders used today for sound. Electrical signals—the broadcast video and audio signals of television—are impressed through a recording head onto the magnetically treated surface of a plastic tape. As the tape is drawn across the recording head, the head continuously changes the magnetic polarity of the magnetic particles on the tape so that they become a compact code of the original signal. This pattern will remain indefinitely on the tape during subsequent playbacks, until it is desired to "erase" the signals electronically and use the tape again to receive another set of signals.

For playback, the tape is drawn across the same head or a similar one. The magnetic code on the tape causes an alternating current to flow in the windings around the reproducing head, creating a duplicate of the original signal.

TV on tape

While the principles are similar to those of sound tape recording, creation of a practical television tape recorder raised many complex engineering problems for whose solution no precedent existed. While sound tape recorders must accommodate signals in a frequency range of up to 20,000 cycles per second, the video signals of black-and-white television extend up to 4,000,000 cycles per second—200 times the frequency range of the familiar sound tape recorder. With the addition of color, at least twice as much pictorial information must be carried as is required for black-and-white television.

Other problems overcome included the design of circuits to feed the video signals into the recording heads and to carry the signals away during playback into monitors and transmitters, and the construction of a constant speed transport mechanism. The latter is essential to carry the tape at a uniform rate past the recording heads, since a variation of speed by as little as one part in 5 million will produce an appreciable jog in the picture on the face of a 21-inch TV picture tube.

Following the 1953 demonstration, a second television tape recorder was built at the RCA Laboratories for a field-test installation at NBC. This second model, incorporating several improvements over the system demonstrated at Princeton, operates at a tape speed of 20 feet per second and can accommodate a 15-minute TV program on a 20-inch reel, using tape approximately one mil thick. The tape itself, with a width of ½-inch, carries six recording channels to accommodate each of the three primary color signals of red, green, and blue, high frequency signals, the synchronizing signal, and the audio signal that carries the sound accompanying the picture.

Flame Ceramics

A novel process for coating a wide variety of substances — by feeding powdered ceramic materials through a simple flame gun—has been developed at Armour Research Foundation of Illinois Institute of Technology, Chicago.

Coatings resulting from the process—called "Flame Spray Ceramics"—are superior to those produced by the metallizing processes because of their greater resistance to heat and chemical stability.

The technique of application is similar to that required for the metallizing processes. "Flame Spray Ceramics" are sintered layers of refractory and chemically inert materials, such as aluminum oxide or zirconium oxide.

The spray coatings do not require that the metal or other base be heated unduly—as opposed to ordinary ceramic coatings which require heating both metal and ceramic to high temperatures.

Since the two basic "Flame Spray Ceramic" coatings—aluminum oxide and zirconium oxide—are stable oxides, they cannot oxidize further.

The alumina coating is harder than tool steel and unusually adherent in thicknesses up to about

the challenge ahead

Industry's demand for lower costs of manufacture offers a promising future to the progressive-minded engineering graduate.

The machine designer who knows how to utilize materials to best advantage will find great demand for his services. That's because the cost of material constitutes a good share of the ultimate cost of a product.

An efficient machine design is one that utilizes the fewest pounds of the least expensive metal that will give required service life.

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1. Steel is 2 to 3 times stronger than gray iron. Only one-third the amount of metal is needed for equal strength in tension.

2. Steel is 2½ times as rigid as iron. Only 40% of the amount of material is needed for equal rigidity.

3. Pound for pound, steel costs a third as much as iron.

As a result, when steel is used to its best advantage, the cost of material amounts to approximately 15% of the cost of iron required for equal rigidity. (40% x ⅓)

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Engineering students wishing to keep abreast of rapid developments in design may obtain literature on application of welded steel by writing:

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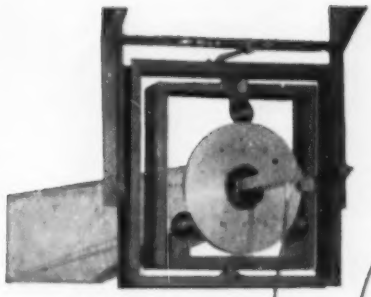
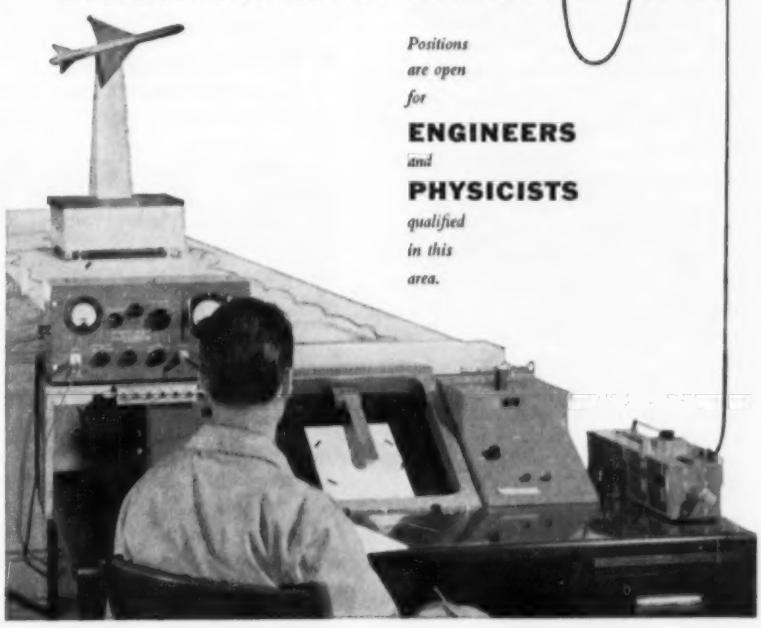


MICROWAVES



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qualified in this area.

The Microwave Laboratory at Hughes conducts fundamental research and long-range development in the field of microwave components and techniques. The antenna program is concerned with research on linear and two-dimensional arrays of slot radiators; transmission and radiation of surface-guided waves; very high resolution radar antennas; and the development and engineering of airborne communication, navigation and fire control antennas.

Instrumentation is developed for new measuring equipment to meet needs of the program. This has included development of automatic impedance and antenna pattern recorders, microwave power supplies stabilized in amplitude and frequency, microwave circuitry, and microwave applications of ferrite devices.

Scientific Staff Relations

HUGHES
RESEARCH AND DEVELOPMENT LABORATORIES
Culver City, Los Angeles County California

10 mils. If applied more heavily, residual stresses may cause coating failure on sudden heating or cooling.

The coating appears to be extremely effective for protecting metals, such as steel and even aluminum, against high temperature erosion such as that encountered in rocket nozzles.

The hardness of the coating suggests its use for protecting soft metals—aluminum, die-cast alloys, or mild steel, for instance—against erosion and abrasion in pump impellers and housings, fan blades and turbines, and piping subject to cavitation.

The alumina coating is electrically insulative, and Bradstreet anticipates its use in the manufacture of high-temperature process equipment. The coating is poorly wetted by certain molten metals, and preliminary tests show it to act as a satisfactory permanent mold coating for aluminum casting.

In this last respect, the zirconia coating should be even better, since it is more refractory and inert than alumina. Although the zirconia coating is somewhat softer and more difficult to apply, its resistance to corrosion and heat is outstanding.

The coating may find use in rockets, flame ducts, burner equipment, and as a liner for troughs, feeders, molds, and other foundry equipment.

Like all sprayed coatings, "Flame Spray Ceramics" have a residual porosity of about 10 to 15 per cent and alone do not provide perfect protection against chemical corrosion of the underlying material.

However, various additives to the two basic coatings improve their protective action, and this can be improved further by overcoating with recent ARF-developed "Solution Ceramics," or by co-spraying with soft metals.

Several other applications of "Flame Spray Ceramics" are already shown to have some value:

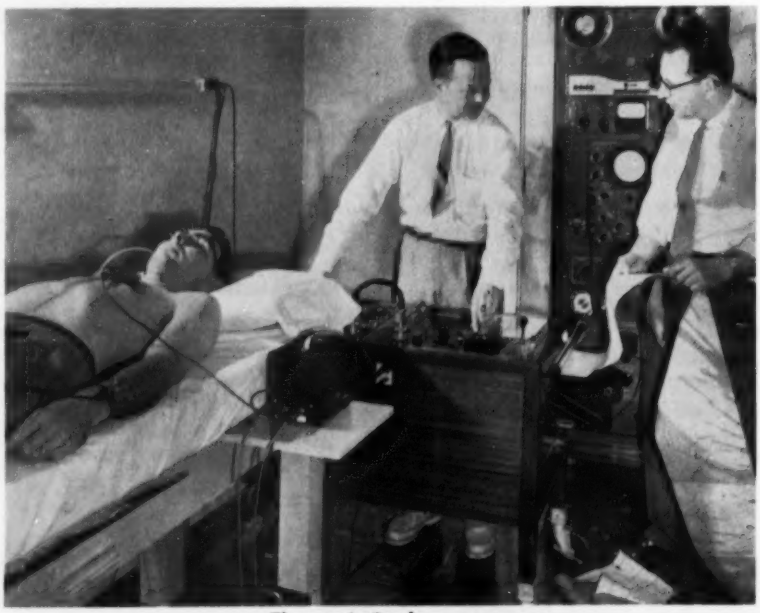
—Thermal protection of engine parts.
—Increasing wear—and skid-resistance of metal treads and gratings.
—Coating on graphite for reducing erosion, oxidation, and wear.
—Decorative surface coating.
—"Wettable" coating for oil burner pans and grates.
—Catalyst coating for certain flame equipment.
—Anti-heat protection for aircraft parts.

Continental Coatings Corporation of Illinois, 2333 S. Michigan Avenue, Chicago 16, has signed a license agreement with the Foundation in the service contract applicator field for use of ARF patents in the development.

The agreement gives Continental Coatings the right to sub-license other organizations throughout the country in the contract applicator field.

An Electronic Stethoscope

Some of the heart's sounds which physicians cannot hear through their stethoscopes now can be seen with the Electro Stethograph, a device developed cooperatively by Dr. Dale Groom (center) of the Medical College of South Carolina and General Motors Research Laboratories. A sensitive pickup on a patient's chest (left) detects these low frequency sounds so they can be recorded on a direct writing device which Joseph B. Bidwell of General Motors Research Laboratories is checking at the right. Medical researchers believe these inaudible sound patterns may be of "potential clinical significance" in studying heart diseases and defects.



Electronic Stethoscope

Graduate Study Program Developed

Plans for a program of graduate education for scientists and enginers in the Greater Hartford area were announced in May, 1955, by Dr. Livingston W. Houston, president of Rensselaer Polytechnic Institute, and H. M. Horner, president of United Aircraft Corporation.

The graduate center will open next September. It will be operated by Rensselaer to the same standards and under the same rules and regulations as the graduate program now conducted on the College's Troy, New York, campus. United Aircraft Corporation this week is concluding negotiations for the purchase of Foxmart in suburban South Windsor, now under lease to its Pratt & Whitney Aircraft division for use in developing a nuclear powerplant.

That facility, with its 22,000 square feet of floor space and its six acres of land, will be given outright to Rensselaer. The Foxmart building will be prepared this summer to house the graduate activities. The nuclear powerplant work now under way at Foxmart will be transferred to other Pratt & Whitney Aircraft facilities in the Hartford area.

Dr. Houston said that the Rensselaer Polytechnic Institute will

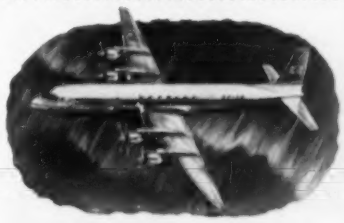
F4D, "SKYRAY"— only carrier plane to hold official world's speed record

A4D, "SKYHAWK"— smallest, lightest atom-bomb carrier

RB-66 — speedy, versatile jet bomber

A3D, "SKYWARRIOR"— largest carrier-based bomber

C-124, "GLOBEMASTER"— world's largest production transport



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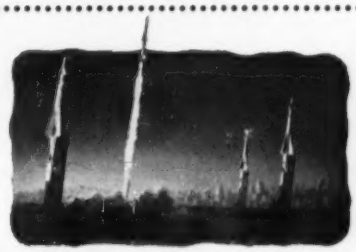
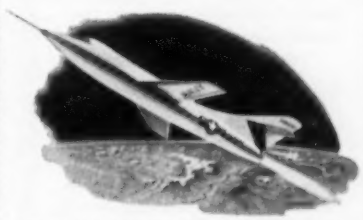


"NIKE"— supersonic missile selected to protect our cities



D558-2, "SKYROCKET"— first airplane to fly twice the speed of sound

At DOUGLAS you'll be joining a company in which the three top executive officers are engineers...you'll be associated with men who have designed the key airplanes and missiles on the American scene today! Nothing increases an engineer's ability faster than working with other engineers of top calibre.

Not only is Douglas the largest manufacturer of commercial aircraft in the world, but it also produces outstanding aircraft and missiles for *every* branch of the armed services! This diversity, besides giving you job security, provides unequalled opportunity for the engineer with an eye to the future.

Challenging opportunities now exist in the following fields:

Mechanical design
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Weapons delivery
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Hydraulics
Stress analysis
Servo mechanisms
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Electronics
Mechanical test
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Brochures and employment applications are available at your college placement office.

For further information relative to employment opportunities at the Santa Monica, El Segundo and Long Beach, California divisions and the Tulsa, Oklahoma division, write today to:

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3000 Ocean Park Blvd.... Santa Monica, California

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Federal Telecommunication Laboratories

A Division of International Telephone and Telegraph Corporation
500 Washington Avenue, Nutley, N. J.

staff the new graduate center with some of its top faculty members, who will be assisted by a number of specially qualified scientists and engineers from the company. Instruction will be mainly in the field of aeronautical engineering, mechanical engineering, and applied mechanics. In addition, there will be opportunities for some courses in metallurgy, management, nuclear chemistry and physics, mathematics, electronics, and other areas important in broadening the background of the applied scientist and engineer. The initial program will run for at least five years to allow an adequate opportunity for an evaluation of its worth.

"We are happy to undertake this program," Dr. Houston said. "We feel certain that the graduate studies will substantially increase the productivity of engineers and scientists who are essential to the nation's continued advancement and prosperity. This process might well supply the answer to the demand by industry for more immediate technological manpower. The studies will recognize the fact that an engineer is essentially an applied scientist and the program's overall objective will be to help working engineers and scientists to grow and develop in maturity through opportunity to extend their knowledge of the basic sciences."

The graduate center's original capacity will be about 200 students. Ultimately the center will be open to Hartford area residents seeking a master's or doctor's degree in engineering or some related field of science. In its first year of operation, however, it is expected that the bulk of the enrollment will comprise engineers from Pratt & Whitney Aircraft, where the region's most critical shortage of engineers and scientists has existed for several years. Subsequently, a larger proportion of engineers from United's Hamilton Standard division and the company's research department will be admitted, as well as residents of the Hartford area, even if it requires considerable expansion of the first year's enrollment.

"This program should not be confused with the usual company training-on-the-job program," Mr. Horner explained. "Modern technology is moving so rapidly, particularly in the multitude of sciences supporting aviation, that we must offer our working engineers an opportunity to broaden their background in the basic sciences.

"The new Hartford center will provide the successful candidate with an advanced master's or Ph.D. degree equivalent to any that can be earned at the very finest university graduate schools. If the working engineer in Hartford goes away to graduate school, we lose him for at least one to two years. We decided that it was best to bring a graduate center here to met this continuing problem. It is extremely gratifying that a school of Rensselaer's distinguished reputation has agreed to establish and conduct the Hartford activity."

Dr. Houston said that Rensselaer probably will establish, under its board of trustees, a group of Hartford men to act as a board of advisors for the graduate center. The state education authorities of New York and Connecticut have both approved and encouraged the project.

City Planning

A team of 10 Cornell graduate students in city planning has completed a master plan for nearby Cortland, N. Y. The project was part of their final year of professional training.

Their 156-page report detailing the changes they propose for Cortland was released on May 26 at a dinner meeting attended by the mayor, city officials and civic leaders.

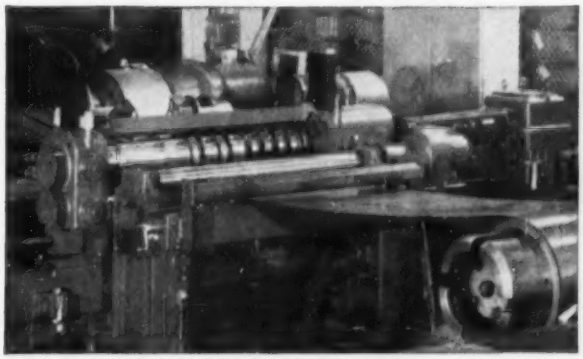
The 34 original drawings and maps printed in the report were on exhibit for two weeks in the reading room of the Cortland Public Library.

Relocated factories, suburban shopping centers, a civic center, a municipal stadium, parks, county buildings and parking areas are among the students' ideas.

A "project phasing chart" lists the changes according to their urgency and practicality. The report schedules the work over a 20-year period, and includes detailed proposals for a city planning board and zoning ordinances.

Another page for **YOUR BEARING NOTEBOOK**

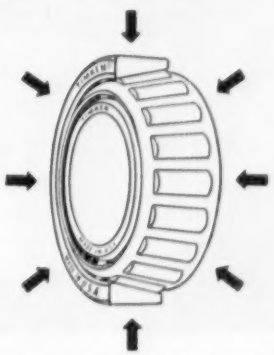
How to keep cutters aligned on high-speed coil slitter



Company engineers had the problem of keeping the cutters on this Stamco Coil Slitter operating accurately at high speeds. It meant keeping them in rigid, positive alignment. To take the heavy combination of radial and thrust loads required, they specified mounting the cutter arbors on Timken® tapered roller bearings.

Tapered design lets Timken® bearings take both radial and thrust loads

Because of their tapered design, Timken bearings can take radial or thrust loads or any combination. And because the load is carried along a full line of contact between rollers and races, Timken bearings have extra load-carrying capacity.



Want to learn more about bearings or job opportunities?

Some of the engineering problems you'll face after graduation will involve bearing applications. For help in learning more about bearings, write for the 270-page General Information Manual on Timken bearings. And for information about the excellent job opportunities at the Timken Company, write for a copy of "This is Timken". The Timken Roller Bearing Company, Canton 6, O.

TIMKEN
TRADE-MARK REG. U. S. PAT. OFF.
TAPERED ROLLER BEARINGS

NOT JUST A BALL ○ NOT JUST A ROLLER ⬭ THE TIMKEN TAPERED ROLLER ⬭
BEARING TAKES RADIAL ⟠ AND THRUST ⊣⊢ LOADS OR ANY COMBINATION ✳

NEW **DEPARTURES OF TOMORROW**

Today, New Departure *ball* bearings are used by 14 leading manufacturers of washers and driers. Wherever there's a moving part, New Departures assure accuracy, low upkeep, longer life.

Maybe it's hard to imagine a home laundry that washes, dries, irons, folds. But it's even harder to imagine this wonder—or any other—working without *ball* bearings . . . New Departures.

In fact, New Departure *ball* bearings play an important role in just about *every* product with moving parts. For more than 50 years, manufacturers everywhere have counted on New Departure for bearings.

Why this confidence? It's a matter of living up to a name. It means being *first* with new departures—like the Sealed-for-Life *ball* bearing. And New Departure will be ready tomorrow with the *finest* bearings . . . *first!*

NEW DEPARTURE • DIVISION OF GENERAL MOTORS • BRISTOL, CONNECTICUT

NEW DEPARTURE
BALL BEARINGS

NOTHING ROLLS LIKE A BALL

SLIDING DOWN THE WAYS at Groton, Conn., goes the USS Nautilus, newest and fastest member of our underseas fleet. During welding, Worthington heavy-duty turning rolls rotated the hull sections.

How the world's first atomic sub was welded

Welding the hull of the USS Nautilus, world's first atomic submarine, presented a tough problem.

Submerged-arc automatic welding seemed to be ideal for the job. Question was—could you rotate the hull sections of the Nautilus to take advantage of this fast, high-quality welding method?

Worthington's answer to General Dynamics Corporation's Electric Boat Division, builder of the Nautilus, was the largest turning roll ever built.

The result? Welding of the Nautilus hull was accomplished in record-breaking time — and cost less than originally estimated. Unchanged, the Worthington roll set-up is also being used in the construction of the nation's second atomic sub, the USS Sea Wolf.

Turning rolls for submarines aren't all that Worthington makes. The long list of Worthington-designed, Worthington-built equipment includes air conditioning units, construction machinery, compressors, Diesel engines, steam power equipment and, of course, pumps of all kinds. For the complete story of how you can fit into the Worthington picture, write F. F. Thompson, Manager, Personnel and Training, Worthington Corporation, Harrison, New Jersey. You may be glad you did.

4.25 B

See the Worthington representative when he visits your campus

See the Worthington Corporation exhibit in New York City. A lively, informative display of product developments for industry, business and the home. Park Avenue and 40th Street.

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REFRACTORY CRUCIBLES
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PITTSBURGH, PA.

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TYPE SH-D — 5000 VOLT TRAILING CABLE

For supplying power to electric shovels, dredges, etc.
Shielded to assure protection to personnel and equipment.

Without insulated wire and cable, our civilization as we know it would be unable to function. CRESCENT Wires and Cables are produced with modern equipment to the most exacting specifications. Every foot is subjected to searching electrical tests during manufacture and in the finished form.

CRESCENT INSULATED WIRE & CABLE CO.

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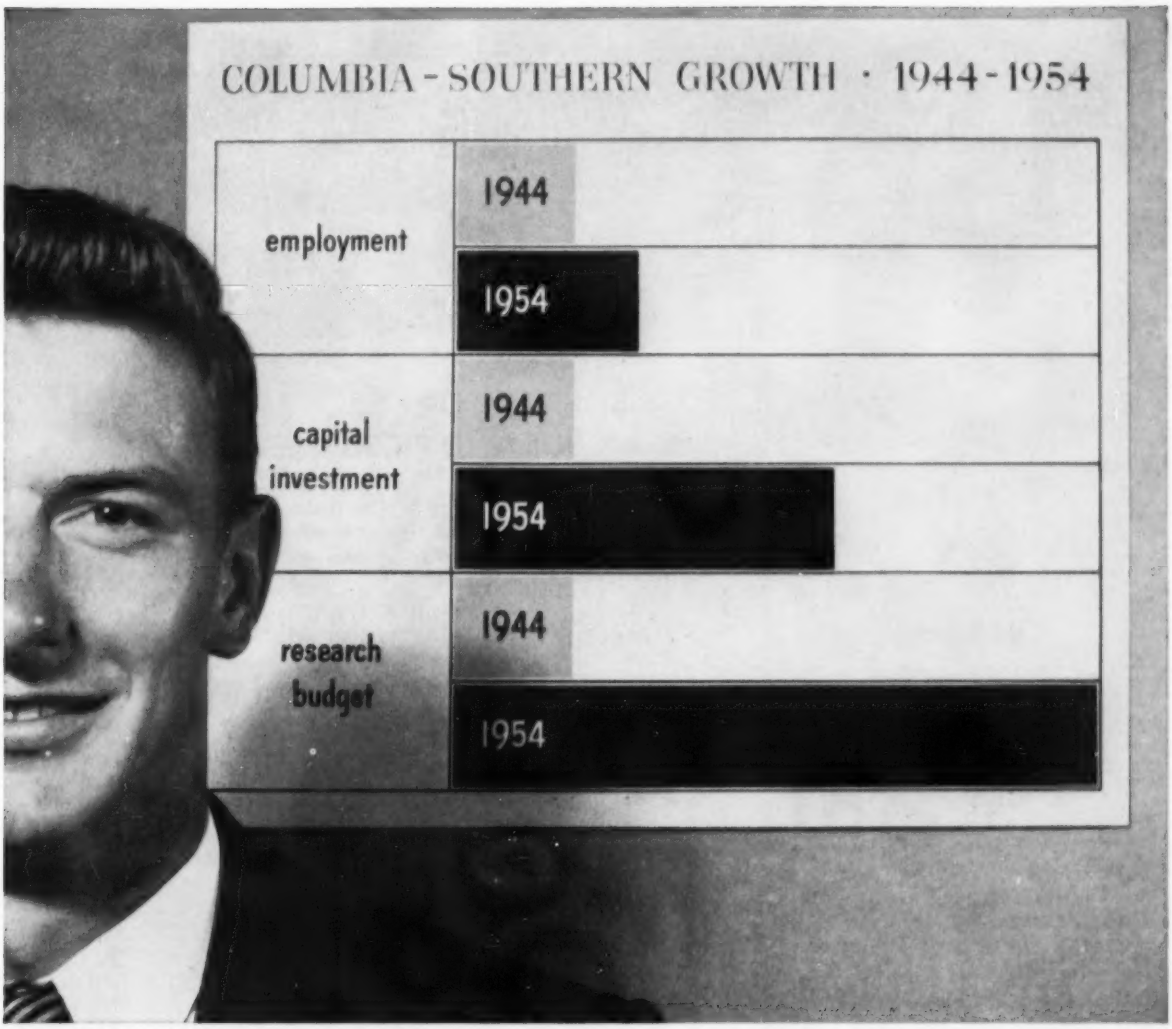

COLUMBIA-SOUTHERN...for men who want to grow!

To a young man looking for opportunities, perhaps the most important fact about a company is its rate of growth, present and prospective. In a company which has become static, advancement is largely dependent on vacancies occurring through death or retirement. In a *growing* company, new openings for able men are being created constantly, and advancement is commensurate with ability.

Since 1925 the chemical industry has grown at an average rate of about 10% a year, compared to 3% for all industry. Future growth, at a more rapid rate than the rest of industry, is predicted by authoritative studies.

Columbia-Southern is growing not only in response to increasing demand for its present products, but also as a result of the steady development of new products. The company's management firmly believes in the importance of research and development and has given evidence of that belief by expanding research facilities and increasing research and development budgets.

Columbia-Southern's growth is an open-end process; as goals are reached, new goals are set. Even now new products and processes are in every stage of evolution, from nebulous ideas in the minds of research chemists to pilot plant operations and production plant designs. That's why Columbia-Southern needs men who can grow with it.

For further information, write now, Dept. P at our Pittsburgh address or any of the plants.

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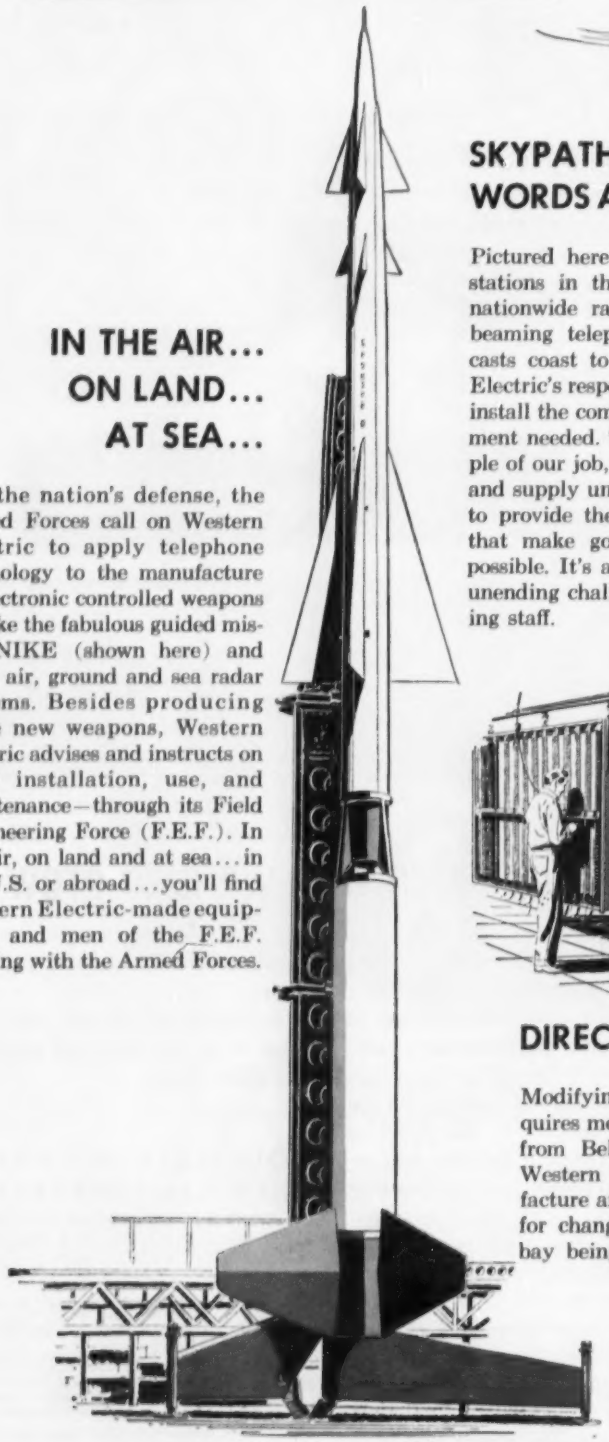
CREATIVE ENGINEERING

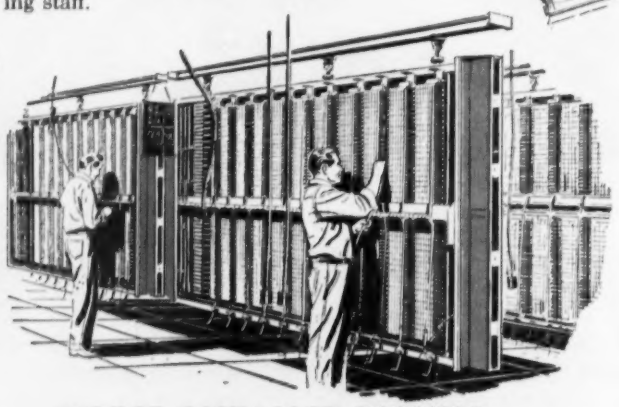
SKYPATH FOR WORDS AND PICTURES

Pictured here is one of the many stations in the Bell System's new nationwide radio relay system for beaming telephone calls and telecasts coast to coast. It is Western Electric's responsibility to make and install the complex electronic equipment needed. This is another example of our job, as the manufacturing and supply unit of the Bell System, to provide the thousands of things that make good telephone service possible. It's a job that presents an unending challenge to our engineering staff.

IN THE AIR... ON LAND... AT SEA...

For the nation's defense, the Armed Forces call on Western Electric to apply telephone technology to the manufacture of electronic controlled weapons . . . like the fabulous guided missile NIKE (shown here) and other air, ground and sea radar systems. Besides producing these new weapons, Western Electric advises and instructs on their installation, use, and maintenance—through its Field Engineering Force (F.E.F.). In the air, on land and at sea... in the U.S. or abroad... you'll find Western Electric-made equipment and men of the F.E.F. working with the Armed Forces.





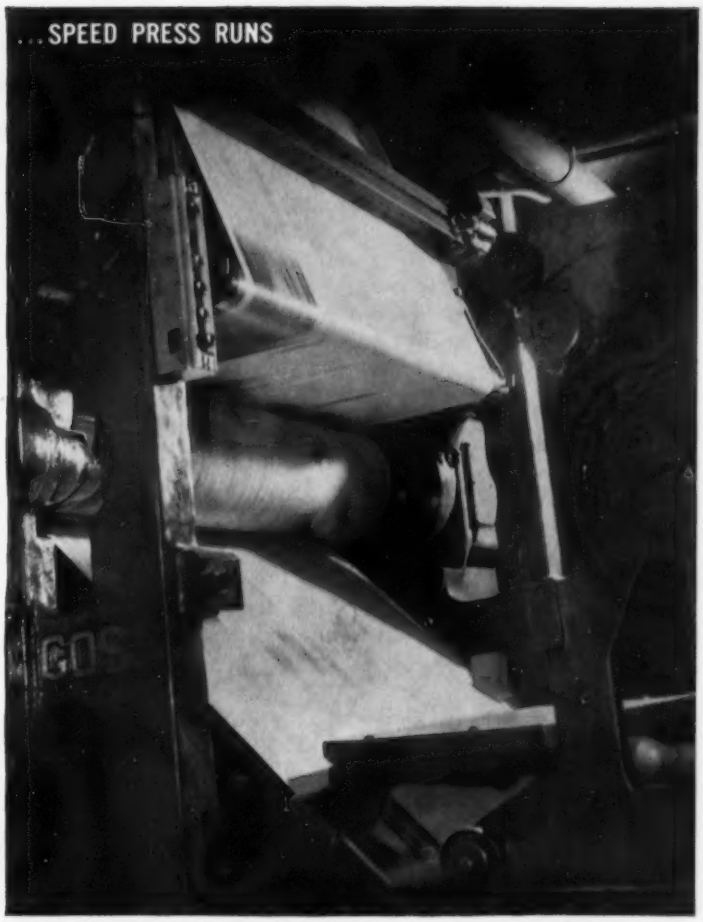
DIRECT DISTANCE DIALING

Modifying telephone systems for nation-wide dialing requires months of make-ready. Working with technical men from Bell Laboratories and Bell telephone companies, Western Electric engineers develop and plan the manufacture and installation of the intricate equipment needed for change-overs. Shown here is an automatic switching bay being manufactured in one of Western's 16 plants.

Western Electric

MANUFACTURING AND SUPPLY UNIT OF THE BELL SYSTEM

HOW HERCULES HELPS...



QUICK DRYING INKS are as important as press speeds in getting large quantity printing jobs off on schedule. For every type of printing requirement—whether it be high speed or specialized—there's a Hercules resin or film-former to assist the ink maker in achieving the best possible formulation for the purpose.

RECENT RESEARCH shows that nonionic surface-active agents make earth soak up water more readily, hold on to it longer. Hercules nonionics, now being used for this purpose, may provide a key to better growth of lawns, flowers, gardens, and farm crops.

AN INVITING POOL takes more than water. As part of the regular maintenance program the sides of the pool must be painted with a protective coating that resists continual submergence. For such uses, and wherever coatings must withstand the challenge of water, acid or alkali, paints based on Hercules Parlon® (chlorinated rubber) give longer service at lower long-term cost.

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SYNTHETIC RESINS, CELLULOSE PRODUCTS, CHEMICAL COTTON, TERPENE CHEMICALS, ROSIN AND ROSIN DERIVATIVES, CHLORINATED PRODUCTS, OXYCHEMICALS, EXPLOSIVES, AND OTHER CHEMICAL PROCESSING MATERIALS.

STRESS and STRAIN...

Strictly from Gibbon

. . . In his famous book *The Decline and Fall of the Roman Empire* we find the following quote:

"With the venerable proconsul (Gordian), his son was likewise declared emperor. His manners were less pure, but his character was equally amiable with that of his father. Twenty-two acknowledged concubines, and a library of sixty-two thousand volumes, attested the variety of his inclinations, and from the productions which he left behind him, it appears that the former as well as the latter were designed for use rather than ostentation."

* * *

'Ere! 'Ere!

In a debate in the British parliament where a Laborite was defending the medicine program, he was being heckled by well-trained Tories in the gallery. As he expounded the benefits of paternalistic government medicine, he boomed: "Why in Britain today we have more bonny babies than ever before. And why . . . ?"

Before he could answer his rhetorical question, one unrespectful heckler shouted. "Private enterprise."

* * *

Stove Lid Philosophy

Mark Twain once said, "One should be careful to get out of an experience only the wisdom that is in it and stop there, lest we be like the cat that sits down on the hot stove lid.

"She will never sit down on a hot stove lid again, and that is well. But also she will never sit down on a cold one any more."

* * *

Judge: "So your name's Joshua, eh? You're not the Joshua that made the sun stand still, are you?"

Culprit: "Lor' no, Judge. Ah'm de Joshua dat made de moonshine."

* * *

Of all the wolves upon this earth
The ones who've cause to brag
Are Chase & Sanborn. They alone
Have dated every bag.

The minister called at the Jones home one Sunday afternoon, and little Willie answered the bell. "Pa ain't home," he announced. "He went over to the golf club."

The minister's brow darkened, and Willie hastened to explain:

"Oh, he ain't gonna play any golf. Not on Sunday. He just went over for a few highballs and a little stud poker."

* * *

"Dad," said the small boy, "why isn't a man allowed to have more than one wife?"

"My son," replied his father, "when you are older you will understand that the law protects those who are incapable of protecting themselves."

* * *

It was the sleepy time of the afternoon. The prof. droned on and on formulae, constants and figures. An engineer, sitting in the second row, was unable to restrain himself and gave a tremendous yawn. Unfortunately, as he stretched out his arm he caught his neighbor squarely under the chin, knocking him to the floor. Horrified, he bent over the prostrate form just in time to hear a murmur, "Hit me again, Sam, I can still hear him."

* * *

A timberman on an early spring trip wandered unkowningly into the maple syrup district of Vermont. Taking a stroll in the woods one day he noted a lot of buckets hanging on the trees. "Gosh a'-mighty," he exclaimed in astonishment, "they sure have sanitary dogs around these parts."

* * *

Waiter: (To customer eating soup): "May I help you, sir?"

Diner: "What do you mean, help me? I don't need any help."

Waiter: "Sorry, sir. From the sound I thought you might wish to be dragged ashore."

Walking with a friend one day, a professor passed a large fish shop where a fine catch of codfish with wide open mouths and staring eyes were arranged in a row. The professor suddenly stopped, lookd at them, and clutching his friend by the arm exclaimed: "Heavens, that reminds me, I have a class in CE this hour!"

* * *

Not So High Up

One of the favorite Minnesota stories concerning the famous Doctor Mayo tells of a pompous millionaire who, seeing Dr. Will Mayo crossing the lobby, bustled up to him importantly. "Are you the head doctor here?" he asked.

"No," replied Dr. Will. "My brother is the head doctor. I am the belly doctor."

* * *

The Old Ones are the Best

One of the most disconcerting fluffs ever delivered by a radio announcer occured during a visit made by the Governor of the Virgin Islands to Washington, D. C.

Describing the event, the beaming newscaster, who shall never again be the same, said, "Today the White House received a special guest in the person of the Virgin of Governor's Island."

* * *

"Why is your car painted blue on one side and red on the other?"

"It's a great scheme. You should hear the witnesses contradicting each other."

* * *

No wonder the little duckling
Wears on his face a frown,
For he has just discovered
His first pair of pants
Were down.

* * *

When you put on your cute rayon scanties
Do they crackle electrical chanties?
Don't worry, my dear,
The reason is clear,
It's just that you have amps in your panties.

Westbound Rio Grande freight in Ruby Canyon of Colorado River.

The freight rolls away an hour sooner

because photography cuts yard bookkeeping

The Denver and Rio Grande Western Railroad microfilms its waybills in minutes, cuts running schedules, saves costs in train idling time.

You don't find a Rio Grande freight idling at the terminal while waybills are copied by hand. Instead, Recordak Microfilming copies them. Then they're put aboard and the train is off in just about one-fifth the time it used to take, thus saving hours of valuable crew and train time. Then the wheel reports are made up from the films and teletyped ahead.

Railroading is but one of over a hundred types of businesses now saving money, time and space with microfilming. It is one of the fast growing and widely used ways photography works for industry.

Small businesses and large are finding that photography helps in simplifying routine procedures, in product design, in personnel relations. It improves production, saves time and cuts costs.

Graduates in the physical sciences and in engineering find photography an increasingly valuable tool in their new occupations. Its expanding use has also created many challenging opportunities at Kodak, especially in the development of large-scale chemical processes and the design of complex precision mechanical-electronic equipment. Whether you are a recent graduate or a qualified returning service man, if you are interested in these opportunities, write to Business & Technical Personnel Dept., Eastman Kodak Company, Rochester 4, N.Y.

Eastman Kodak Company, Rochester 4, N.Y.

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